جامعة خليفة
Khalifa University

ISSUE 01 | FEBRUARY 2024

explorer

A MISSION TO MARS

KHALIFA UNIVERSITY OF SCIENCE AND TECHNOLOGY'S JOURNEY OF SPACE DISCOVERY AND EXPLORATION

UNLOCKING THE SECRETS OF REGENERATIVE MEDICINE

AI AND BREAKTHROUGH IMAGING TECHNOLOGY COULD PAVE THE WAY FOR BIOARTIFICIAL KIDNEY DEVELOPMENT

ANDRIY ONUFRIYENKO/ MOMENT/ GETTY IMAGES

DRIVING A SUSTAINABLE FUTURE

At Khalifa University, we're playing a pivotal role in creating a greener and more sustainable future for our community and beyond. Find out more about our COP28 engagement initiatives at ku.ac.ae/sustianability-cop-28

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ABOUT THE COVER

Coloured scanning electron micrograph (SEM) of a resin cast of kidney glomeruli capillaries and the larger blood vessels supplying them with blood. Glomeruli play a critical role in filtering waste products from the blood.

COVER IMAGE:
STEVE GSCHMEISSNER/SPL / GETTY IMAGES

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ABOUT KHALIFA UNIVERSITY

The internationally top-ranked Khalifa University of Science and Technology is the one university in the UAE with the research and academic programs that address the entire range of strategic, scientific and industrial challenges facing the UAE's knowledge economy transformation and our rapidly evolving world.

Its world-class faculty and state-of-the-art research facilities provide an unparalleled learning experience to students from the UAE and around the world. The university brings together the best in science, engineering and medicine in the UAE, to offer specialized degrees that can take promising high school graduates all the way to top-rated doctorate degree holders.

ABOUT KU EXPLORER

KU Explorer covers the scientific achievements of the internationally top-ranked Khalifa University of Science and Technology. The website is updated weekly with new stories on a range of topics.

Whether you're a student, academic, industry professional or simply interested in learning more about the latest scientific advancements from Khalifa University of Science and Technology, KU Explorer has something for everyone.

We invite you to join us on this journey of discovery and exploration. You can stay up to date with our latest research news by following us on social media or subscribing to our newsletter.

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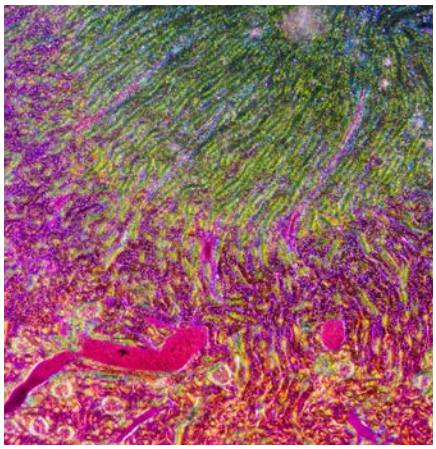

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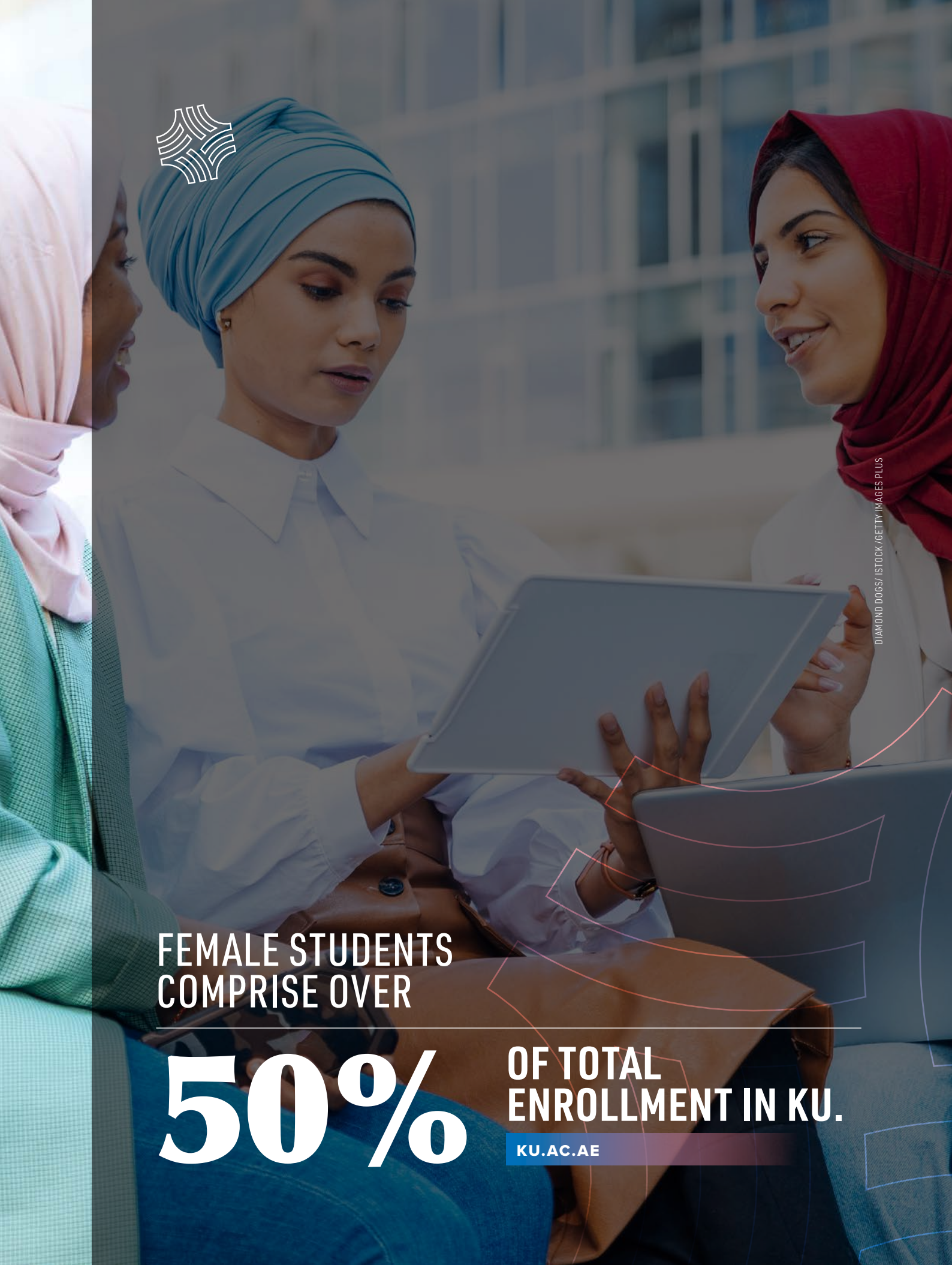

DIAMOND DOGS/ ISTOCK/GETTY IMAGES PLUS

FEMALE STUDENTS
COMPRISE OVER

50%

OF TOTAL
ENROLLMENT IN KU.

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EDITOR'S LETTER

Welcome to the inaugural issue of *KU Explorer*, an annual publication serving as a window into the cutting-edge research emerging from Khalifa University of Science and Technology's 20 specialized research centres.

Our cover stories shed light on the recent achievements accomplished by Khalifa University in the fields of health and wellness. Unlocking the secrets of regenerative medicine, Peter Corridon talks about how his research into organ function has been helped by camels; and his quest to develop a fully functioning bioartificial kidney, so that animal tissue is no longer needed. We look at ways in which machine learning can detect early signs of kidney damage, assess how advanced imaging techniques can provide insights into organ scaffold viability, and proudly unveil the first-ever genomic analysis of the Emirati diabetic population—a groundbreaking achievement shedding light on diabetic kidney disease in our country.

We also highlight a pioneering study that reveals how a specific class of drugs holds the power to safeguard patients suffering from a form of heart failure, significantly reducing the risk of cardiac arrest and death. Every stride we make in the fields of health, environmental preservation and technological advancement hinges on the bedrock of materials science. We explore the future of wearables, examining how data harnessed from these devices can not only assess mental and emotional well-being but also predict the development of these vital facets in an individual's life.

Next we look at the United Arab Emirates' first cosmic endeavor, marking a significant milestone in the quest for space exploration. Building upon the resounding success of the Hope mission, Khalifa University is setting the stage for an enduring legacy in space and planetary science. We look at the fresh imagery beamed back by the Hope Mission, unraveling novel insights into Martian climate patterns. These revelations not only enhance climate and weather forecasting but can also pave the way for future missions to the Martian frontier. We then delve into the intricate dance of dust particles in Saturn's ring system, unveiling the complexities of planetary dynamics.

Transitioning from celestial realms and back to Earth, we turn to water—a resource that is becoming increasingly scarce amidst the looming specter of climate. Our dedicated researchers at KU are pioneering breakthrough technologies in water desalination and wastewater management, in an effort to ensure that water remains a lifeline for generations to come.

But the road to climate change mitigation in our region is fraught with challenges. A thought-provoking study led by Steve Griffiths, KU's Senior Vice President for Research and Development and Professor of Practice, uncovers a stark reality. With the exception of five nations, the Eastern Mediterranean and Middle Eastern (EMME) region lacks greenhouse gas emission reduction strategies that could be considered equitable with regard to meeting the objectives of the 2015 Paris Agreement, a pact designed to safeguard our planet from a perilous temperature rise of 1.5°C or more above pre-industrial levels.

Our journey extends to the domain of aerospace engineering, where graphene-based sensors are poised to redefine the game across aerospace, automotive and marine applications, promising revolutionary breakthroughs. These stories are just a glimpse of the extraordinary research you'll find in this issue, showcasing Khalifa University's pursuit of knowledge and progress. KU Explorer, where knowledge knows no boundaries, and possibilities are limitless, underscores our commitment to being a catalyst for innovation, economic development and social prosperity in the United Arab Emirates and the world.

Steve Griffiths
Senior Vice President for
Research and Development

Machine learning detects early signs of kidney damage

Artificial intelligence systems have been taught to detect abnormal cell structures invisible to the human eye, potentially speeding up diagnosis of kidney failure.

Acute kidney injury (AKI) imposes a significant financial burden on healthcare systems, considering the number of hospitalizations and other associated costs.

Luckily, machine learning techniques could change all this by detecting subtle signs of kidney damage, potentially enabling early intervention and treatment before they turn into serious problems.

Researchers at Khalifa University working with international colleagues have shown that artificial intelligence (AI) systems can detect abnormal cell structures that are virtually imperceptible to the human eye. Using existing biopsy materials taken from patients, the technique could speed up diagnosis of kidney failure in hospitals.

"There are differences in the onset of this type of injury that we would not be able to detect, whereas the machine can," says Peter Corridon, who specializes in kidney physiology and who led the project.

To test the AI's ability to detect kidney damage, the researchers showed the computer images of cells from rat organs. Some images showed healthy tissue and others showed damage to proximal tubule cells, the most common cell type in the kidney, which deals with metabolic waste products. Damage to these cells is associated with the abrupt drop in renal function seen in AKI and other hard-to-treat and potentially life-threatening consequences.

When provided with information about which tissue images were taken from animals with kidney injury, the AI was able to find signature changes in the shape and structure of the proximal tubule cells associated with the pathology.

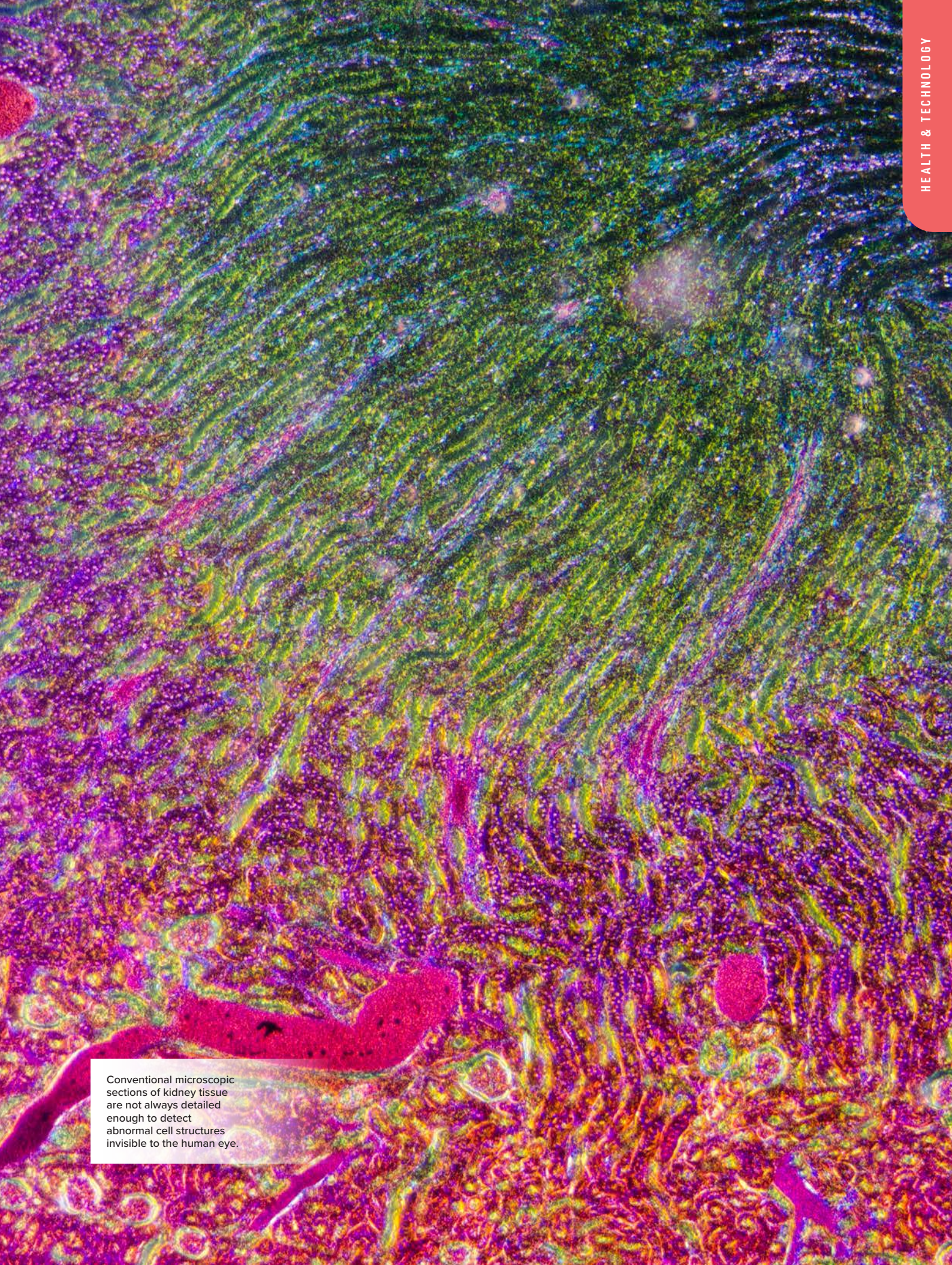
The study could pave the way for the development of a "sensitive, accurate, and affordable computer-aided diagnostic system that might be an essential addition to current nephropathology practices," the researchers say.

One reason AKI is hard to diagnose lies in the limitations of conventional microscope images of kidney tissues taken in biopsies, which are not detailed enough to pick up small changes in cell nucleus structure. To improve the quality of the scans, the researchers used innovative techniques called gray-level co-occurrence matrix analysis and discrete wavelet transform. These methods generate images with increased texture, providing the AI with more features and patterns to associate with the disease state.

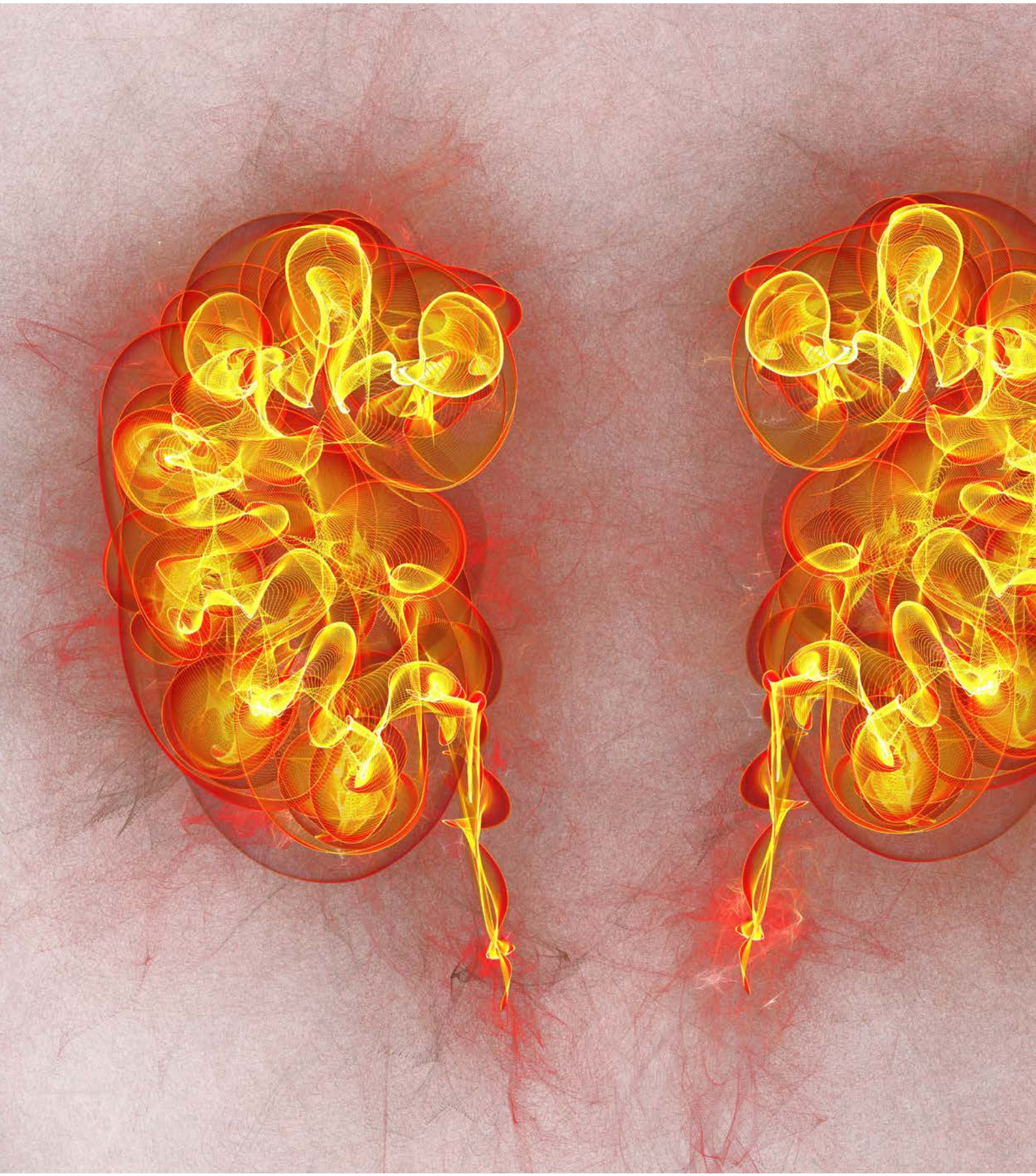
The next step for the research team is to test the AI system with more unlabelled images, allowing it to distinguish between healthy and diseased tissue. "Now we are working with a pathologist and doing this in a blind formation," Corridon says. "So having the pathologist tell us this, and the machine tell us this, and seeing who is correct."

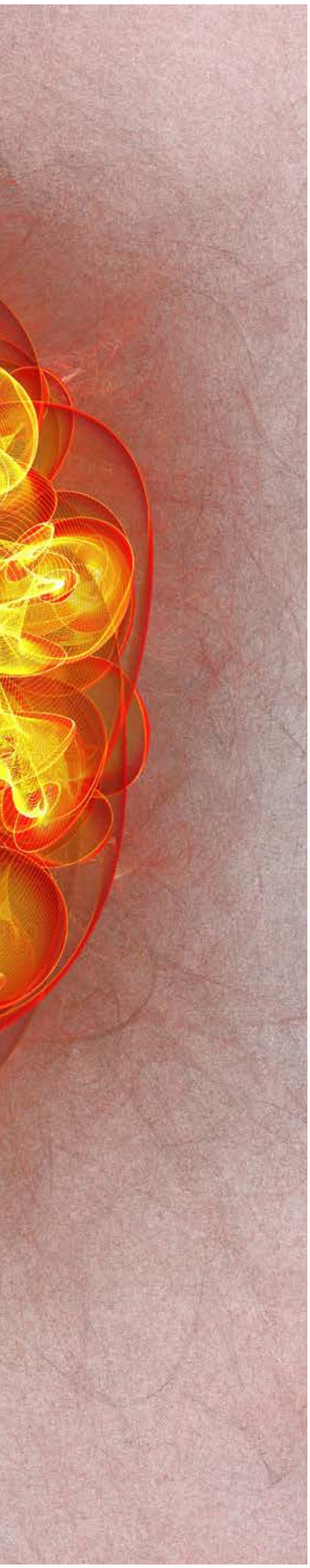
Pantic, I., Cumic, J., Dugalic, S. et al. Gray level co-occurrence matrix and wavelet analyses reveal discrete changes in proximal tubule cell nuclei after mild acute kidney injury. *Scientific Reports* **13**, 4025 (2023).

DEFUN/ ISTOCK/ GETTY IMAGES PLUS



Conventional microscopic sections of kidney tissue are not always detailed enough to detect abnormal cell structures invisible to the human eye.





MEHAU KULYK / SPL/ GETTY IMAGES

Unlocking the secrets of regenerative medicine

Peter Corridon talks about how his research into organ function has been helped by camels; and his quest to develop a fully functioning bioartificial kidney, so that animal tissue is no longer needed.

When Peter Corridon relocated his research on kidney physiology from the United States to Abu Dhabi in 2019, he faced an unusual challenge. Studies worldwide typically use pigs to analyze organ function because of their similarity in size to human organs. “But we don’t have a lot of pigs in the Middle East,” he says.

After a few phone calls and a visit to the local slaughterhouse, Corridon—assistant professor of immunology and physiology in the College of Medicine and Health Sciences at Khalifa University—secured a steady supply of sheep kidneys. He would later adapt the research further to look at organs taken from local camels. “Given the lack of resources a camel has, it should not be able to stand up and function. It really shouldn’t. So, their kidneys are special,” he says.

Following his PhD studies at Indiana University, Corridon went on to work at Wake Forest University in North Carolina under James Yoo and Anthony (Tony) Atala; revered figures in regenerative medicine. “They are highly respected. You just say Tony’s or James’ name and doors open for you,” Corridon says.

For Corridon, the opening came at Khalifa University, where he now specializes in how blood vessels grow and behave. He has also expanded his expertise to include work on the eye. One research interest, for example, is to discover why cell signaling encourages blood to flow in the kidney, but restricts blood flow in parts of the eye, including the cornea.

“You cannot have blood vessels inside your cornea, you become blind,” he explains. “So, for us, it’s all about learning how

EDWIN REMSBERG/ THE IMAGE BANK/ GETTY IMAGES

"Camels have a very special oval-type red blood cell. It's not like ours and may hold secrets to help us overcome debilitating diseases."

all these mechanisms work."

Despite the diversity in the sources and types of organs used in his research, there is a common objective: to better understand and treat conditions in people. And even the unusual camel could offer useful insights in regenerative medicine.

"Again, technically speaking, a camel should have a lot of ocular diseases. It's in the desert being hit with dust, with this heat, it should be blind," Corridon says. "But it's not. And we're trying to figure out some of the things that are inherent in the camel that can help maintain eyesight for us. They have a very special oval-type red blood cell. It's not like ours and may hold secrets to help us overcome debilitating diseases."

Another of Corridon's long-term research goals is to develop a fully functional bioartificial kidney. This would help address the growing need for kidneys for transplants and provide an animal-free platform for lab studies of the organ.

Corridon's research includes a technique called decellularization, which removes the native cellular components from human and animal kidneys leaving the extracellular matrix scaffold of the original organ. These can then be used as templates to build bioartificial tissue on and to monitor blood vessel growth.

Was establishing an academic career in the United Arab Emirates difficult? The heat can be overpowering, Corridon says, but that is compensated for by the warmth of the welcome he has received. "Honestly, these people here have been the best human beings I've met," Corridon says. "They're just so welcoming and happy to have you. They're just really good people."

Imaging blood flow through cell-free kidneys

An advanced imaging technique is providing insights into organ scaffold viability, which could help reduce donor organ shortages in future.

Research at Khalifa University has imaged blood flowing through a kidney without its cells for the first time; an important step towards the development of bioartificial organs for research or transplant. The research was made possible thanks to the innovative technique of intravital microscopy, which enables the imaging of the internal processes inside living animals.

This pioneering study, conducted in rats, harnessed an innovative combination of whole organ decellularization, transplantation and intravital microscopy. It showed how the blood could flow without clotting, despite being exposed to collagen inside the cell-less kidney. Organs divested of their internal cells in this way, commonly referred to as scaffolds, are a popular option in bioengineering research, as they can then be filled with cells from a specific patient.

"Remarkably, this thing can actually withstand blood flow," says Peter Corridon, a kidney specialist at the university's College of Medicine and Health Sciences, who carried out the new research. "So, it gives us insight into how we might be able to build a better, stronger, or more resilient structure as we repopulate the scaffold with cells."

The findings, published in *Scientific Reports*, indicate that the advanced imaging technique "may provide novel insight into scaffold viability, and identify ways to promote scaffold longevity and vasculogenesis in whole decellularized organs and help reduce donor organ shortages within the foreseeable future."

In approved experiments, Corridon removed kidneys from rats, eliminated the internal cells from the organs, and then transplanted the scaffolds back into the animals. These kidney scaffolds were not empty or hollow; they retained their internal structure of blood vessels. But with no cells, the blood that entered the kidney scaffold was exposed to collagen, which would usually be expected to trigger the blood-clotting process.

"Technically speaking, when you have this scaffold and you have blood flowing, it should clot, it should not work whatsoever," says Corridon. "And oddly enough, this thing flowed for days." After that, the clotting process did kick in and the internal structure of the kidney scaffold broke down.

The results are important for two reasons. First, they show that blood could continue to flow while cells begin to regrow inside a kidney scaffold. Second, as the blood flows it could carry with it the stem cells and other components needed to help the kidney cells grow and form tissue.

"It was painstaking work," Corridon says, adding that there remains some way to go before the development of a fully artificial organ. "The kidney has about 50 cell types. And it's hard to get every cell and every structure right to create all these complex systems," he explains.

Corridon, P.R. Capturing effects of blood flow on the transplanted decellularized nephron with intravital microscopy. *Scientific Reports* **13**, 5289 (2023).

ED RESCHKE/STONE/GETTY IMAGES

Wearable device data shows promise in predicting future emotional and mental states

Data gathered by wearable devices can be used not only to assess mental and emotional well-being, but could also soon predict how these issues may be developing in an individual's life.

As low-cost mobile and wearable sensors find increased uses, research is emerging that uses them to track and analyze mental well-being, productivity and behaviors. The lack of open datasets collected in real-world contexts is, however, limiting potential research advances in affective computing and human-computer interaction that rely on such data.

Researchers at Khalifa University have collaborated with colleagues in South Korea to investigate the potential of wearable sensor devices in gathering data that correlates with mental and emotional states. Their study, conducted on a sample of 77 students over seven days, has been compiled into a dataset called K-EmoPhone.

The three-year collaboration between Khalifa University and the Korea Advanced Institute of Science and Technology (KAIST) focused on the regular collection of data aimed at revealing aspects of the participants' mental state, including their emotions, stress and attention levels.

"The connections forged between the Khalifa and KAIST teams will hopefully lead us to further collaborative research to advance potential for our methods to be incorporated into commercial smart devices, such as smart watches and other wearable technology," says Leontios Hadjileontiadis of Khalifa University's Department of Biomedical Engineering.

The study harnessed data from smartphones and commercial consumer wearable devices, which captured environmental and physiological signals, as well as movement patterns. Measurements included parameters such as body temperature, heart rate, skin electrical resistance, light exposure, and caloric expenditure linked to activity and body maintenance.

This direct physiological monitoring was complemented by data from the participants' responses to a smartphone app questioning them about their feelings and activities. The assessments occurred at random intervals up to 16 times each day, allowing the primary sensor data to be contextualized within participants' emotions and activities at different times of the day.

The data was then combined with that from pre- and post-study surveys of the participants' mental and emotional state, especially their ongoing sense of well-being, stress or depression.

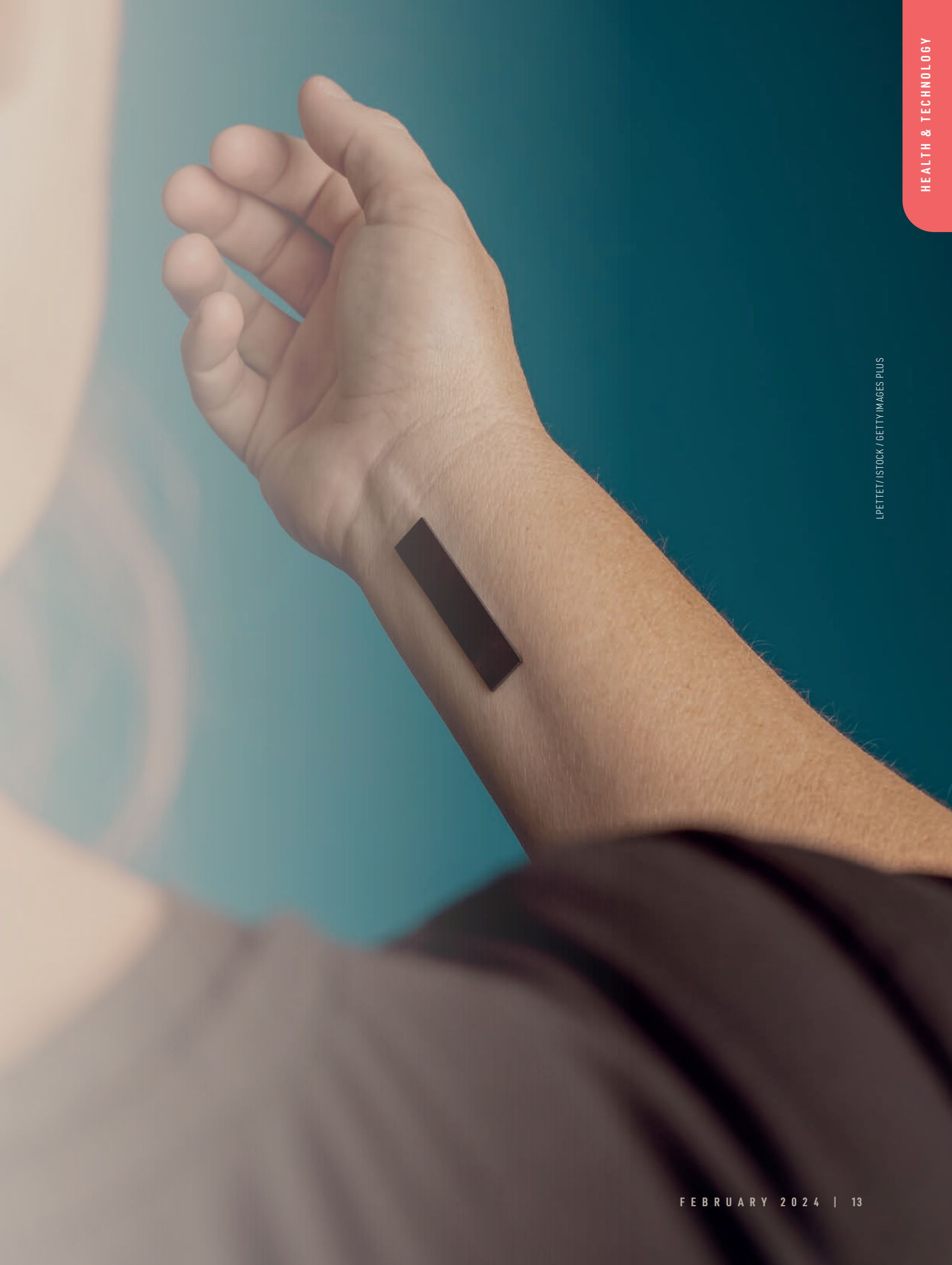
Taken together, the results confirm that data from wearable devices can indeed be used to assess mental and emotional well-being and can also be used to predict how these issues may be developing in an individual's life. The findings advance the understanding of the ability of wearable technology to monitor more subtle aspects of an individual's condition.

"I expect that our work will help develop new opportunities for healthcare professionals and researchers to analyze mental and cognitive states with smartphone and wearable sensor data," says systems engineer Woohyeok Choi of the KAIST team.

The K-EmoPhone procedure and dataset is at a relatively early proof-of-concept stage, and the researchers acknowledge the need to refine the software for broader applicability. They are, however, confident of wider general and commercial opportunities.

"Future enhancements could ensure compatibility with different commercial software systems and seamless integration into existing and emerging wearables such as smartwatches and other devices," says Hadjileontiadis.

Kang, S. et al. K-EmoPhone: A mobile and wearable dataset with in-situ emotion, stress, and attention labels. *Scientific Data* **10**, 351 (2023).



LPETTET/ISTOCK/GETTY IMAGES PLUS

Eliminating the noise in vision technology

An artificial intelligence algorithm that uses few resources could help robotic systems find their way in poor light.

The navigation of robotic systems, such as drones or self-driving cars, requires computer-based vision technology that can accurately perform, even in challenging low-light conditions such as moonlight. This capability is particularly important for applications in defense, law enforcement and space exploration.

Existing technology uses neuromorphic cameras, which are equipped with sensors that mimic the functions of the human retina. Unlike conventional cameras that capture individual frames, neuromorphic cameras report changes in the scene at different time points and, by comparing this information, establish a continuous stream of events. They can operate in low-light conditions, while using extremely limited amounts of power, compared with conventional cameras. However, the performance of neuromorphic cameras is typically hampered by noise.

A team led by Yahya Zweiri, Director of the Advanced Research and Innovation Center and Associate Chair of the Aerospace Engineering Department at Khalifa University, has designed and developed an artificial intelligence algorithm to filter noise from event streams while preserving data from real features in the visual scene.

The algorithm is based on a graph neural network (GNN) with transformers known as GNN-transformers, and uses spatiotemporal correlations between events in the camera's surroundings to detect if an incoming raw event is noise or a genuine feature, such as the edge of an object.

"Unlike conventional cameras that capture individual frames, neuromorphic cameras report changes in the scene at different time points and, by comparing this information, establish a continuous stream of events."

SARAWUT CHAMSAENG/ SHUTTERSTOCK.COM

"The proposed algorithm is the fastest among state-of-the-art models owing to the processing of events efficiently on a central processing unit," says Zweiri. "This eliminates the need for advanced hardware, making the model ideal for settings with limited computational power and resource-constrained platforms."

The GNN-transformer incorporates an EventConv layer, which distinguishes between real activity and noise events by operating on graphs constructed from the camera's raw data. "This captures spatiotemporal events, while accounting for the asynchronous nature of the camera stream," says Yusra Alkendi, a PhD graduate in Aerospace Engineering and member of the team. The model has been tested on publicly available datasets to show that the algorithm works in general settings with different motion dynamics and different lighting conditions.

Alkendi appreciates the supportive research environment at KU. "KU has generously provided me with hands-on research experience using cutting-edge tools and technologies, enabling the shaping of global research and benefiting our community," she says. "The guidance of distinguished professors has led to remarkable milestones, for example, the accolade of Top 1% Journal Publication in August 2022 and other research papers in prestigious engineering journals."

Looking ahead, Zweiri and Alkendi are aiming to improve the performance of neuromorphic vision systems further by combining their algorithm with other event-based computer vision algorithms. These enhancements could encompass self-localization, object detection, object tracking and object recognition, among others.

Alkendi, Y., Azzam, R., Ayyad, A., Javed, S., Seneviratne, L. & Zweiri, Y. Neuromorphic camera denoising using graph neural network-driven transformers, *IEEE Transactions on Neural Networks and Learning Systems* (2022).

Genome analysis provides insights into diabetic kidney disease among the Emirati population

A first of a kind study of Emirati diabetics unveils a gene variant that could contribute to kidney disease susceptibility.

Several Middle Eastern countries have some of the highest rates of diabetes worldwide, along with a worrying prevalence of diabetic kidney disease (DKD), a condition leading to gradual loss of kidney function. Yet little is understood about the underlying genetic factors at play.

Researchers at Khalifa University, in collaboration with the Imperial College London Diabetes Centre in Abu Dhabi and Queen's University Belfast in the UK, have conducted the first genomic analysis of the Emirati diabetic population. The study of 938 unrelated Emirati individuals with type 2 diabetes without DKD, alongside 258 patients who suffer both diseases, sought to understand the link between genetics and susceptibility to DKD.

"Although hyperglycaemia is widely regarded as triggering DKD, numerous other genetic and environmental factors contribute greatly to the disease's progression. As a result, not all individuals with diabetes will experience the development of the disease," explains Wael Osman, from Khalifa University's Department of Biology and first co-author of the study.

The researchers identified a variant in the *CNR2* gene associated with DKD. This variant encodes a protein called cannabinoid receptor 2, which exhibits activity in various parts of the kidney. It plays a role in insulin resistance, inflammation and the excessive scarring of the kidneys known as kidney fibrosis.

Comparative analysis of these findings with data from other global populations found variations in the *CNR2* gene in Japanese people with DKD, but not in British and Finnish populations. These distinctions in genetic makeup among different ethnic groups could potentially lead to differences in DKD predisposition and progression.

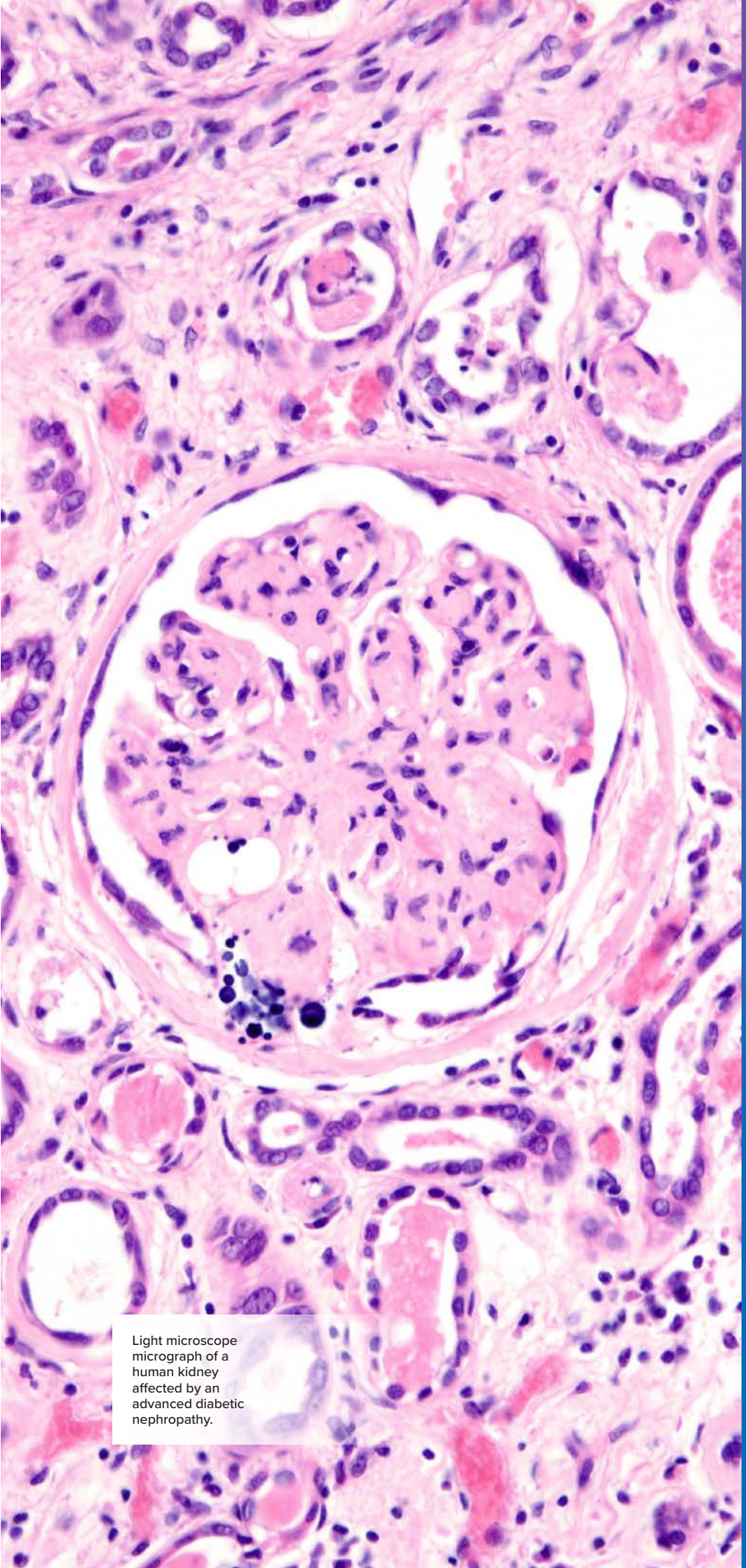
The study shows that this variant of *CNR2* is linked with DKD in the context of type 2 diabetes, a condition typically diagnosed in adults. The correlation was not evident in type 1 diabetes, which tends to develop early in life and is believed to be caused by an autoimmune reaction.

The published findings also hint at the possibility of 11 additional genes with variants linked to DKD. The team acknowledges there is a need for further validation through a broader study that includes multiple ancestral ethnic groups from Middle Eastern populations.

"Although DKD is common among the Emirati population, we're not entirely sure which specific genetic variants are responsible for causing this disease. This study has brought us closer to uncovering why some diabetic patients in the UAE develop kidney problems and others don't," says study leader Habiba Al Safar, from Khalifa's Department of Genetics and Molecular Biology.

"This study has brought us closer to uncovering why some diabetic patients in the UAE develop kidney problems and others don't."

"Since ethnicity and genetics play a role in DKD, one day we may be able to craft therapeutic advancements tailored to specific populations," adds co-author Mira Mousa.



Light microscope micrograph of a human kidney affected by an advanced diabetic nephropathy.

11.8%
Percentage of the Emirati population between the age of 20 and 79 living with diabetes.

10.8 to 61.2%
Prevalence ranges of DKD among type 2 diabetes patients in the Middle East region.

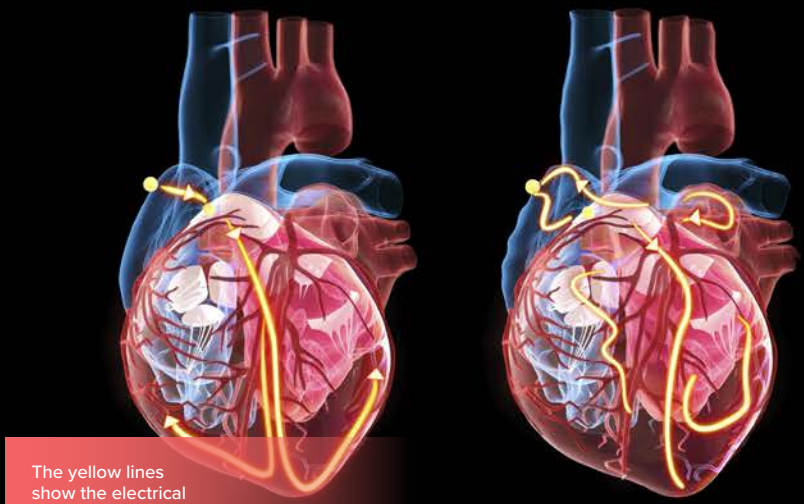
990,900
Total cases of diabetes in Emirati adults.

1. Osman, Wael et al. A genome-wide association study identifies a possible role for cannabinoid signalling in the pathogenesis of diabetic kidney disease. *Scientific Reports* **13.1** 4661 (2023).
2. Aldukhayel, A. Prevalence of diabetic nephropathy among Type 2 diabetic patients in some of the Arab countries. International Journal of Health Science, 2017
3. UAE Vision 2021.

JOSE LUIS CALVO MARTIN & JOSE ENRIQUE GARCIA-MAURIÑO MUZQUIZ/ ISTOCK/ GETTY IMAGES PLUS

Beta blockers take on new life in heart disease

Beta blockers have been shown to regulate heart function when it is most needed in a growing group of patients at risk of cardiac arrest.



The yellow lines show the electrical system of the human heart. At right is an arrhythmia and atrial fibrillation.

TUMEGGY/ SPL/ GETTY IMAGES

Heart failure is a lifelong condition in which the heart muscle can't pump enough blood to meet the body's needs. Different types of heart failure are categorized based on the ejection fraction, which indicates the percentage of blood pumped out of the heart with each heartbeat. One form, known as heart failure with preserved ejection fraction (HFpEF), involves a maintained ejection fraction with no significant decline and is becoming increasingly common. It is often associated with sudden death due to abnormal heartbeats called ventricular arrhythmias.

A study by researchers at Khalifa University suggests that beta-blocker drugs could protect patients with this form of heart disease, reducing the risk of cardiac arrest and death.

Heartbeat is controlled by an interplay between the sympathetic and parasympathetic nervous systems. The sympathetic system accelerates heart rate in response to stressful situations while the parasympathetic system acts to maintain a steady and slower heart rate.

Beta blockers inhibit overstimulation of the sympathetic nervous system. While they are widely used in patients with reduced ejection fraction, their effects on patients experiencing HFpEF have been unclear until now.

Researchers at Khalifa University studied beta-blocker administration in patients with HFpEF by monitoring the effects on heart activity at different times of the day using electrocardiogram (ECG) testing.

"We detected improved control of heart-rate variability with beta blockers, especially at times associated with high cardiac risk," says biomedical engineer Leontios Hadjileontiadis of the Khalifa team. "This suggests that beta-blocker therapy might significantly protect patients with HFpEF."

Hadjileontiadis emphasizes that HFpEF is a variable condition that requires treatment tailored to the specific needs of each patient. Insights gained from this study could help to personalize treatment. By monitoring the patients regularly over 24 hours, the study identified a particularly significant improvement and overall decreased risk of a dangerous cardiac event in the early morning. At that time of day, the risk is increased due to a surge in activity by the sympathetic nervous system.

"Prescription of beta blockers could target high-risk time periods to effectively regulate the heart's function when it's most needed," says Hadjileontiadis.

The initial results were from a small, short-term study of 56 treated patients and 17 controls. The team is planning to carry out longer-term treatment and monitoring, and will explore different beta blockers, as well as the effects of variables such as patients' sex, age, ethnicity and other medical conditions. The researchers are also developing artificial intelligence approaches with the potential to refine the interpretation of heart-function data and guide the choice of treatment options.

Saleem, S. et al. Investigating the effects of beta-blockers on circadian heart rhythm using heart rate variability in ischemic heart disease with preserved ejection fraction. *Scientific Reports* **13**, 5828 (2023).

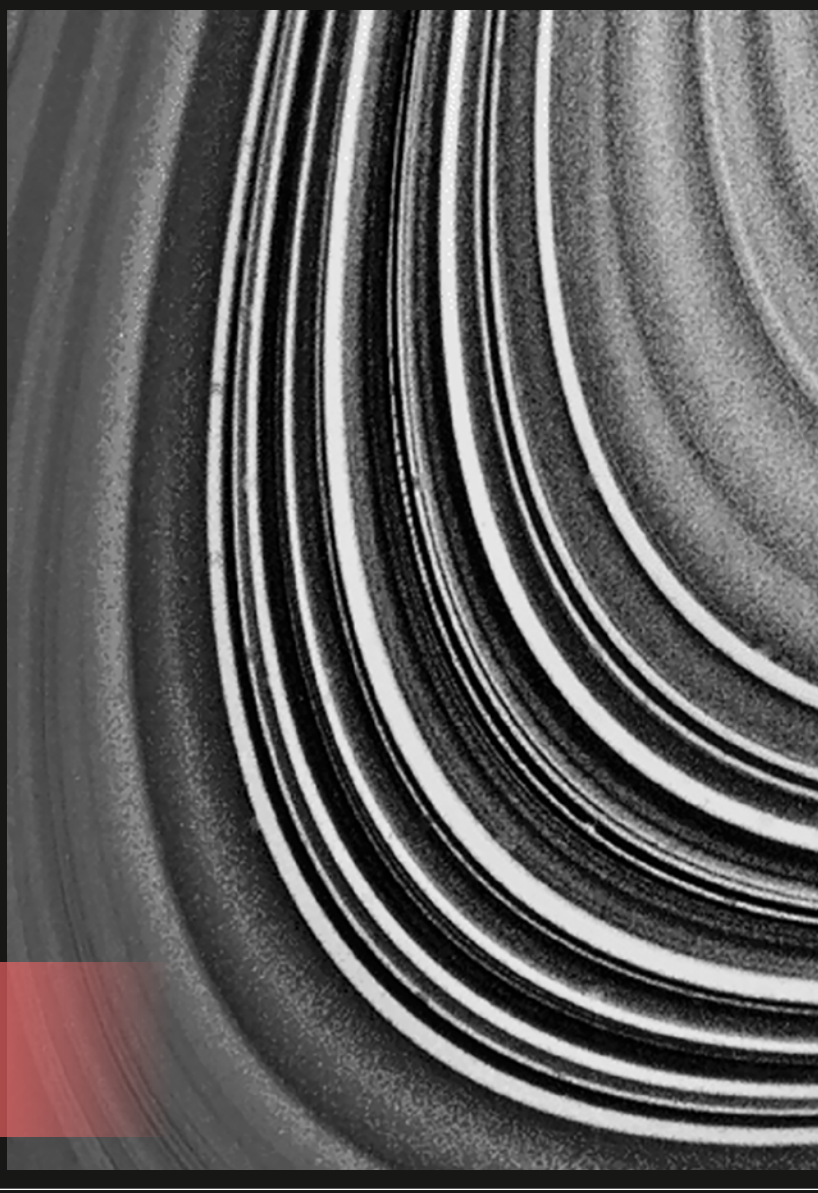
SCIENTIFIC DEFINITIONS AND FACTS

Heart failure with preserved ejection fraction (HFpEF)

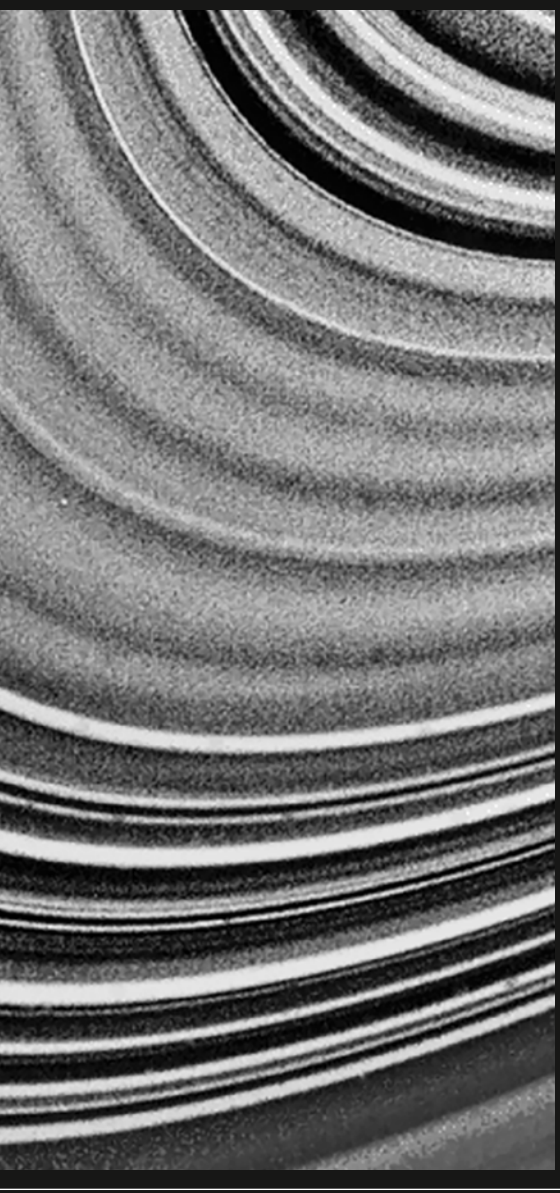
is a form of heart-failure that involves a maintained ejection fraction with no significant decline and is becoming increasingly common. It is often associated with sudden death due to abnormal heartbeats called ventricular arrhythmias.

Simulating Saturn's dusty waves

Khalifa University scientists have modelled the complex way that particles of dust oscillate in the dusty environment of the rings surrounding Saturn.



Dust in Saturn's rings can interact with plasma in the planet's magnetosphere to produce tsunami-like waves.



NASA

Outer space is usually thought of as being entirely empty: a cold void. In fact, space can be dusty. Particles, no larger than a tenth of a millimeter, are thrown out by ageing stars and can play a role in planet and star formation. They also form into rings around planets.

Space missions such as Voyager 1, Voyager 2 and Cassini have observed and studied the dusty rings of Saturn, which are much fainter than the rings known to astronomers for centuries. The presence of these rings raises fascinating questions about how charged dust behaves in the planet's magnetosphere.

Kuldeep Singh and Ioannis Kourakis from Khalifa University of Science and Technology, working with colleagues Amar Kakad and Bharati Kakad from the Indian Institute of Geomagnetism, have now developed a numerical simulation that can model the motion of dust in the magnetosphere of Saturn. Specifically, the team investigated the collective oscillations of the dust particles in magnetospheric plasma.

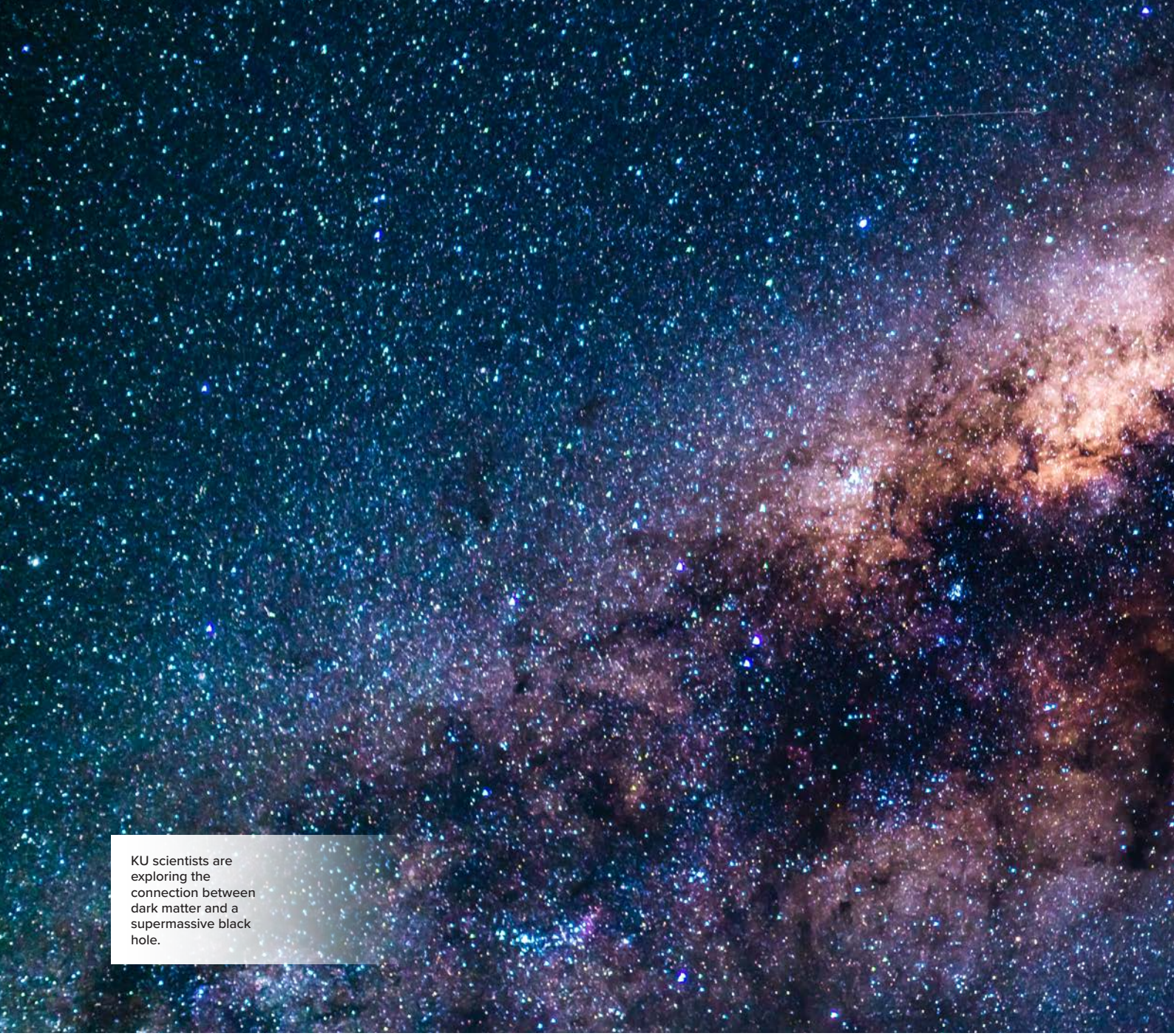
Plasma is composed of electrically charged ions and electrons. The Sun ejects plasma, which crosses the solar system as solar wind. When it reaches a planet's magnetosphere containing dust particles, it creates what is known as a dusty plasma. The interplay between the energetic particles in the solar wind and the charged particles in the magnetosphere creates a slow oscillatory motion in the dust, which is known as a dust-acoustic wave. "Dust acoustic waves occur thanks to the dust providing the necessary inertia while the thermal pressure of the surrounding plasma supplies the restoring force needed to sustain the wave," explains Kourakis. "They are essentially tsunami-like 'solitary' waves in the dusty plasma related to the collective motion of the dust."

Kourakis and his team created a computer model to better understand the evolution and motion of the waves using the power of fluid dynamics. By introducing a localized change in density in their virtual dusty plasma the researchers were able to observe the spontaneous birth of two counter-propagating solitary waves. "The computer simulations allowed us to investigate the role of the dust and of highly energetic, or suprathermal, electrons and ions on the propagation characteristics of dust-acoustic waves," says Kourakis.

"Dust acoustic waves occur thanks to the dust providing the necessary inertia while the thermal pressure of the surrounding plasma supplies the restoring force needed to sustain the wave."

The team focused primarily on an environment corresponding to that of Saturn's magnetosphere, and the results matched well with spacecraft observations and previous theoretical predictions. But they believe their model could also be relevant for other planetary environments where dusty plasmas are present.

Singh, K., Kakad, A., Kakad, B. & Kourakis, I. Fluid simulation of dust-acoustic solitary waves in the presence of suprathermal particles: Application to the magnetosphere of Saturn. *Astronomy & Astrophysics* **666**, A37 (2022).



KU scientists are exploring the connection between dark matter and a supermassive black hole.

Dark matter and the Milky Way

Dark matter could hold key to the nature of a recently discovered supermassive black hole.

Did you know?

The black hole is an estimated mass of 4.1 million times that of the Sun.

AMRIPHOTO/ E+/ GETTY IMAGES

New mathematical solutions to Einstein's field equations, which are central to describing cosmology and astrophysics, provide interesting alternative possibilities for the black hole at the center of the Milky Way. These solutions could indicate that dark matter may play a pivotal role.

For more than 15 years, it has been proposed that a supermassive black hole, known as Sagittarius A*, sits at the center of the Milky Way. This finding earned physicists Reinhard Genzel and Andrea Ghez the Nobel Prize for Physics in 2020. Excitingly, in May 2022, the first observations of Sagittarius A* from the Event Horizon Telescope (EHT), a global network of connected radio telescopes, were released which provide very strong experimental evidence that a black hole is indeed present with an estimated mass of 4.1 million times that of the Sun.

However, the exact nature and origin of this supermassive black hole is still a mystery. One possibility being explored by mathematicians at Khalifa University of Science and Technology in the United Arab Emirates, working with physicists at the Universidad de los Andes in Columbia, is that dark matter could play an important role.

Writing in The European Physical Journal C, Davide Batic, Mojahed Faraji and Marek Nowakowski applied different dark matter profiles and equations of state to the field equations and presented a theoretical analysis of the solutions[1]. The outcome was the prediction that three possible new astrophysical objects could be responsible for the object at the center of the Milky Way—a fuzzy dark matter droplet without a horizon or a black hole with either one or two horizons.

The dark matter droplet solution displays similar behavior to a conventional Schwarzschild black hole, so could provide a plausible explanation that features dark matter.

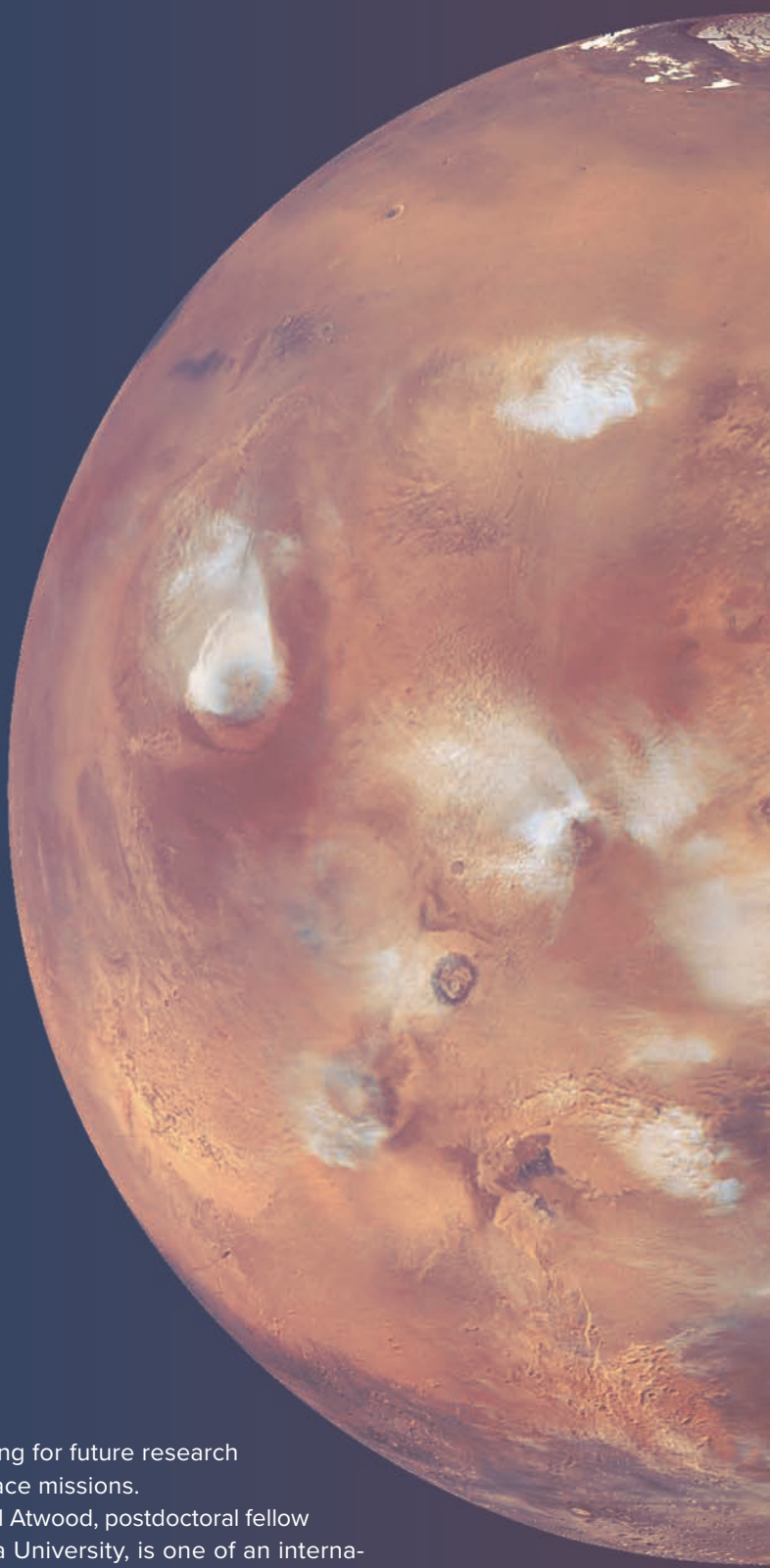
Significantly, the different solutions have slightly varying characteristics which the EHT should be able to test for and identify. In particular, the EHT should have the capability to detect whether the shadow formed by a dark matter droplet is present.

"Some of our solutions could, in principle, replace the standard black hole picture of the galactic center and, at the same time, have the advantage that they have been composed of the main matter ingredient of the universe [dark matter]," says Batic. "We hope that the existence of these gravitational objects may be confirmed or disproved with the help of the EHT."

1. Batic, D., Faraji, J. Mojahed & Nowakowski M. Possible connection between dark matter and supermassive black holes. *European Physical Journal* C **82**, 759 (2022).

Revealing insights into cloud formations on Mars

Analysis of new images taken from the Emirates Mars Mission highlights the daily and seasonal patterns of the Aphelion Cloud Belt.

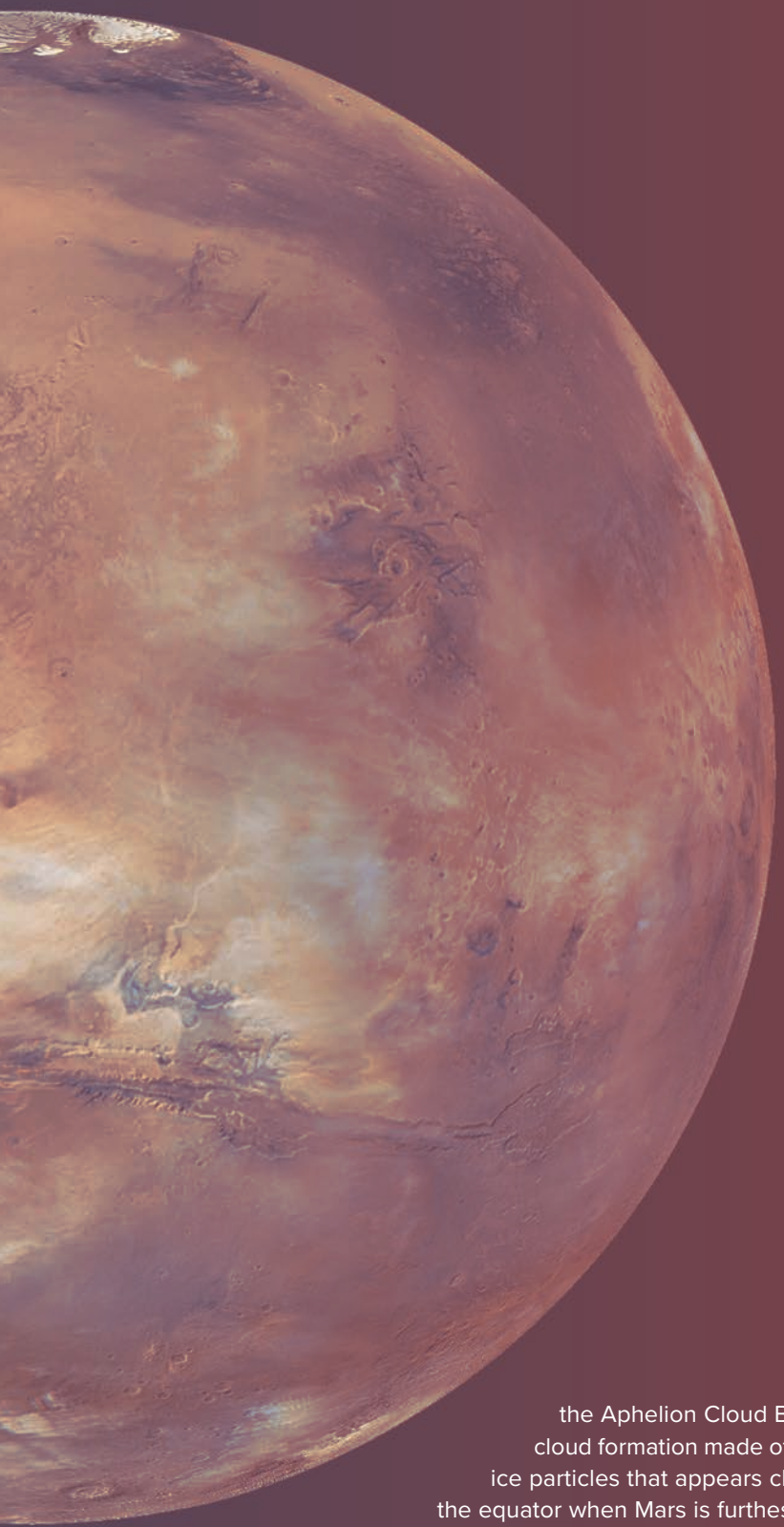


Did you know?

The Aphelion Cloud Belt is a cloud formation made of water ice particles that appears close to the equator when Mars is farthest from the sun.

The Emirates Mars Mission (EMM) is primarily focused on gathering extensive data about the Martian atmosphere, and has been sent into a higher orbit around Mars than many previous missions. The EMM is revealing new knowledge about the climate patterns on Mars, which will improve climate and weather forecasting for future research and surface missions.

Samuel Atwood, postdoctoral fellow at Khalifa University, is one of an international team of scientists involved in analyzing the datasets from the EMM. The team has recently published new findings related to



WORLD HISTORY ARCHIVE / ALAMY STOCK PHOTO

the Aphelion Cloud Belt[1]—a cloud formation made of water ice particles that appears close to the equator when Mars is furthest from the sun. The team analyzed the structure and daily fluctuations of the cloud belt, which is present during spring and summer in the northern hemisphere. Atwood is part of the Khalifa University and University of Colorado-Boulder EMM collaborative research program that launched in 2020.

"Measuring many of the basic properties of clouds, which atmospheric scientists take for granted on Earth, is more difficult on Mars," says Atwood. "EMM's higher orbit allows us to make observations at all local times across a wide surface area, and we can measure dust, water ice clouds, and temperatures across spatial and temporal scales that haven't been examined before."

The team used image data from the Emirates eXploration Imager (EXI) on board EMM, and combined these new images with those taken by the Mars Color Imager (MARCI) on a previous mission. This allowed them to determine the 'ice optical depth'—in other words, how thick each area of cloud is—at different times of the day.

"Cloud thickness is a useful variable to include in weather modelling, but measuring a cloud's mass from space is tricky," says Atwood. "Instead, we can measure how much light passes through the cloud, which gives an indication of how thick it is. If we can learn more about when and where clouds occur, and how extensive they are, this helps us determine the underlying conditions that form them."

Their results show that there were fewer clouds near midday than in the mornings or afternoons. The cloud belt is much thicker and covers much more of the planet in the mornings than at any other time of day, particularly during the Aphelion season—the period in each Martian year when Mars is farthest from the Sun.

"These results will be compared against atmospheric computer models to help identify key processes and understand how we might adjust our models to better match observations," says Atwood. "Ultimately, we want to understand the atmosphere in detail so that we can improve weather forecasting and climate predictions on Mars."

1. Wolff, M.J. et al. Diurnal variations in the Aphelion Cloud Belt as observed by the Emirates Exploration Imager (EXI). *Geophysical Research Letters* **49**, e2022GL100477 (2022).

Detailed profiling of the Martian atmosphere

Data from an infrared spectrometer on board the Emirates Mars Mission allows detailed analysis of atmospheric conditions during the Aphelion season.

Monster dust devils occur as the surface is heated by the Sun, generating warm, rising air currents.

NASA/JPL-CALTECH/UARIZONA

State-of-the-art instruments aboard the Emirates Mars Mission (EMM) spacecraft, together with its relatively high orbit around the planet, are providing scientists with insights into the planet's atmospheric temperature profiles, and the amounts of dust particles, water ice and water vapor present in the atmosphere.

"Many previous missions focused on studying the surface of Mars, which often meant that they observed small regions of the planet at the same local time for all their observations," says Samuel Atwood, postdoctoral fellow at Khalifa University and one of the scientists in the international team analyzing the EMM datasets. "EMM's orbit allows us to see more of the planet at once and to measure the atmosphere at different times of day. This means we can learn more about the daily dynamics of the atmosphere."

"EMM's orbit allows us to see more of the planet at once and to measure the atmosphere at different times of day."

For this study, the team analyzed thermal infrared spectra from the Emirates Mars Infrared Spectrometer (EMIRS)[1]. The spectrometer measures surface temperature, and can also estimate 3D atmospheric temperature profiles in columns from the ground up to around 40 kilometers above the surface. Further, the EMIRS measurements enabled the researchers to estimate the abundance of dust aerosols, water ice and water vapor in the atmosphere.

"It is exciting to learn about the day-to-day atmospheric patterns on Mars," says Atwood, whose team has developed a novel algorithm to interpret the data. "These initial findings show that the planet was relatively cool and cloudy, but with little dust in the air; not surprising given the data was collected during the Aphelion season," the time period in each Martian year when Mars is farthest from the Sun.

Water ice clouds were plentiful, with the Aphelion Cloud Belt prominent, and water vapor reached its maximum abundance at high northern latitudes over the summer solstice. Dust opacity was at its annual minimum, showing a latitudinal gradient with more dust in the northern hemisphere. One surprising feature was a regional dust storm that occurred earlier than expected for the season; the EMIRS measurements showed that atmospheric temperatures in the region increased significantly during the storm.

"The new spatial and temporal scales enabled by EMM provide us with a wealth of data. This study is just the beginning," says Atwood. "Going forward we will be using this information to compare against existing models for the Martian climate and atmosphere, and this will allow us to refine our understanding of how the atmosphere changes over time."

The research being conducted by Atwood is part of the Khalifa University and University of Colorado-Boulder EMM collaborative research program, which launched in 2020.

Smith, M.D. et al. EMIRS observations of the Aphelion-season Mars atmosphere. *Geophysical Research Letters* **49**, e2022GL099636 (2022).

Improved algorithms boost desalination performance

A swarm-intelligence model of hunting behavior is encouraging neural networks to find the best of the best solutions to enhance the dynamic management of desalination processes.

About half of the world's population is likely to be living in water-scarce conditions within the next few years, according to reports from the World Health Organization (WHO) and the United Nations children's charity UNICEF.

Desalination technologies, such as reverse osmosis plants, are an important part of addressing this growing challenge. A research team at Khalifa University, led by Shashikant Patole, has developed a novel machine-learning model that holds the promise of significantly enhancing the dynamic management of such plants.

"It's imperative to accelerate research into improving desalination in order to ensure a sustainable life for humans, animals, and plants," says Patole, adding that this could also help desalination plants run more efficiently.

Modern reverse osmosis (RO) plants use advanced analytics and predictive algorithms to optimize their performance. By dynamically managing factors such as feed flow rate or evaporator and condenser intake temperatures, these systems help maximize the plant's output, saving time, money and energy. Patole and his team set out to improve the models guiding these systems.

Artificial neural networks (ANN), which are a cornerstone of modern machine learning and AI, are the models used to optimize RO plants. But the standard training algorithm can get stuck on a solution that's good enough rather than finding the best overall solution. Patole and his team have explored whether a hybrid model might do better. They used an ANN trained not with the usual algorithm but with a modified version inspired by the hunting behavior of whales.

"We explored the possibility of using the Modified Whale Optimization Algorithm [a popular swarm intelligence algorithm] to overcome the limitations of the training algorithms," Patole explains. "This could improve model performance, enabling better plant modelling and performance."

The team started by identifying the ideal range for a number of key technical features of the model, such as how many hidden layers and search agents it had. Using these parameters, they selected their top 10 best models. They identified one which outperformed the others. This best of the best model was tested against published experimental data from RO desalination plants. In addition to producing better predictions, the new model is more efficient than existing models because it has a simpler structure.

Did you know?

About half of the world's population is likely to be living in water-scarce conditions within the next few years.

The team plans to collect more data from RO desalination plants to assess how well the hybrid models perform with very large data sets.

They also hope to test the improvements in practice.

"Our next step is to develop a lab-scale prototype desalination plant and investigate the parameters experimentally and computationally to increase plant performance and accuracy," says Patole.

Mahadeva, R., Kumar, M. & Gupta, V. et al. Modified Whale Optimization Algorithm based ANN: a novel predictive model for RO desalination plant. *Scientic Reports* **13**, 2901 (2023).

NAVINTAR/ SHUTTERSTOCK.COM

Sustainable solutions to revolutionize wastewater management

A pioneering method of fabricating a catalyst used to remove toxic chemicals from effluent could contribute to sustainable technologies for wastewater management.

With the rising threat of climate change, effective water management is critical for nations to thrive. This is particularly true for an arid country such as the United Arab Emirates, where developing sustainable and eco-friendly methods for treating and reusing wastewater is essential to overcoming water security challenges.

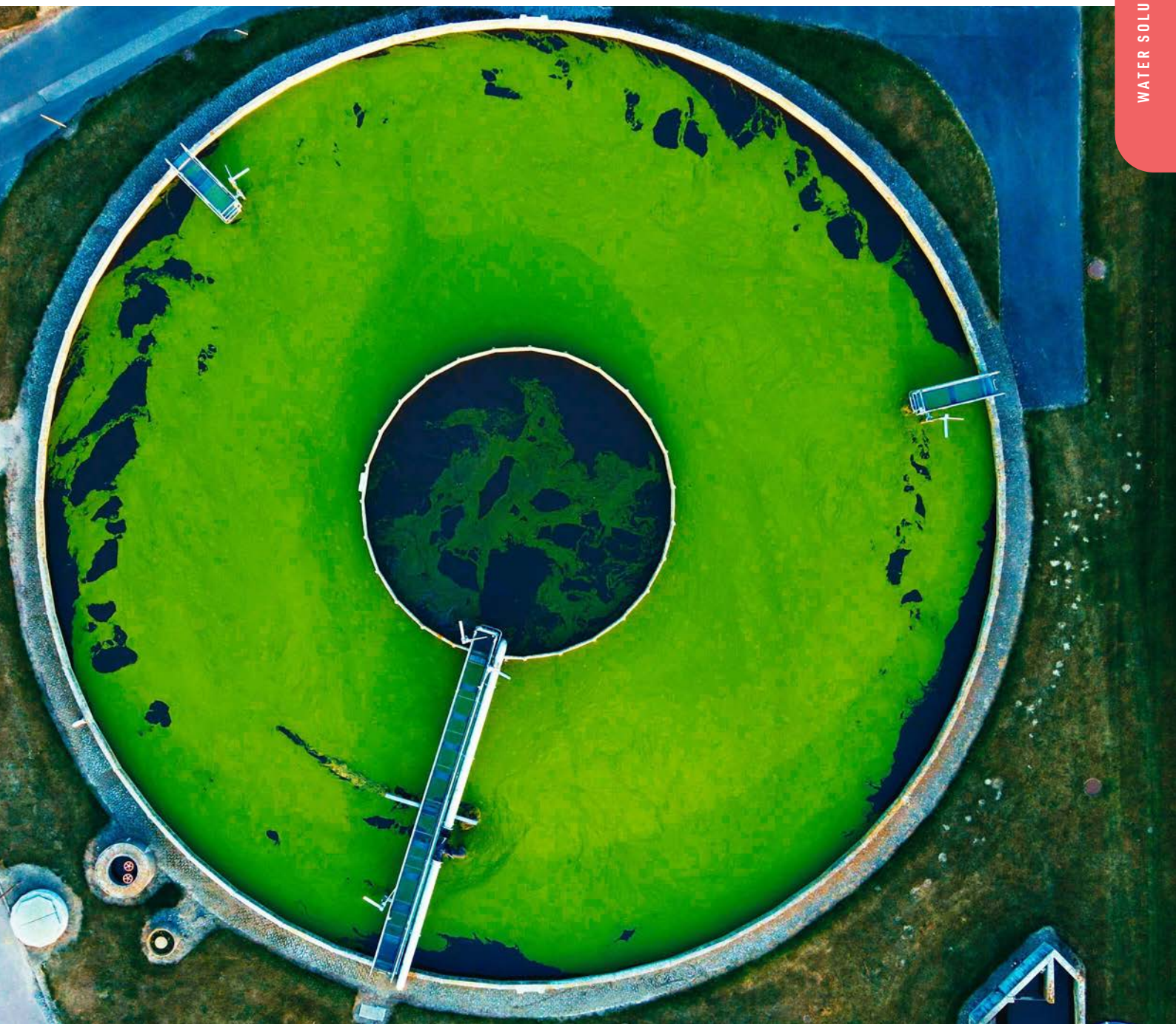
Wastewater management research is a key priority at Khalifa University, where scientists are applying cutting-edge chemistry and nanotechnology in fresh imaginative ways to remove toxic chemicals from industrial effluent, paving the way for sustainable water management solutions.

A vision of sustainability

"Sustainable, green wastewater treatment technologies will play a vital role in meeting our nation's challenges," says Fawzi Banat, Chair of the Department of Chemical Engineering at Khalifa University. "Developing efficient and cost-effective solutions for treating wastewater and reusing both the water and its components for various purposes will provide a secure basis for future growth and development," he adds.

To improve sustainability, wastewater treatment approaches must be optimized to reduce energy consumption and carbon emissions.

"The effectiveness of sustainable treatment approaches also depends on the specific characteristics of the wastewater being treated, and



HENRIK JONSSON / ALAMY STOCK PHOTO

further research is needed to optimize processes that are tailored to the UAE's unique conditions," notes Salma S. Syed, a researcher in the same department.

The UAE is testing green wastewater initiatives—including membrane bioreactors, constructed wetlands and microbial fuel cells—that will help treat wastewater sustainably, according to Banat. "These initiatives aim to contribute to the country's sustainable development while addressing water scarcity and environmental pollution challenges," he explains.

A 'one-pot' stop for hazardous substance removal

One of the primary objectives of wastewater treatment technologies is to prevent the release of hazardous chemicals that would otherwise end up in soils, rivers and seas. One such toxic pollutant is 4-nitrophenol, a potent substance that is primarily used as a pesticide and is frequently found in industrial effluent.

"If not properly treated, 4-nitrophenol pollutes water courses, resulting in catastrophic effects on aquatic organisms by triggering a drop in dissolved oxygen levels and promoting algal growth," ex-

HENRIK JONSSON / ALAMY STOCK PHOTO

plains Syed. “Exposure to 4-nitrophenol can also elicit toxic effects on plants, land animals, insects and birds. We must take appropriate measures to prevent its release into the environment and treat contaminated areas effectively,” she says.

One way of degrading 4-nitrophenol in wastewater is to use gold nanoparticles as catalysts, but to be green their synthesis must be as environmentally friendly as possible. Syed and co-workers recently published pioneering results from a study that introduced a sustainable ‘one-pot’ method for generating uniform, stable gold nanoparticles. Their process uses an unexpected ingredient as a natural reducing agent to form the nanoparticles: an extract from the leaves of the olive tree Olea europea. The extract offers an eco-friendly alternative to conventional chemical-reducing agents.

“Developing efficient and cost-effective solutions for treating wastewater and reusing both the water and its components for various purposes will provide a secure basis for future growth and development.”

“We chose olive leaf extract due to the plant’s abundance, availability and cost-effectiveness,” says Syed. “The extract is rich in various compounds including phenolic acids, flavonoids and oleuropein which possess antioxidant properties that facilitate the reduction of gold ions to form nanoparticles. The extract also helps prevent the nanoparticles from clumping together, which would render them unusable,” she explains.

Various parameters were manipulated to optimize the process, including altering pH, temperature and reaction time. The final method proved to be rapid and efficient, yielding stable, easily reproduced nanoparticles with enhanced catalytic activity.

The team then ran experiments to test the ability of the synthesized nanoparticles to degrade 4-nitrophenol. They created a photocathode that generates and transfers electrons upon light exposure. This method, known as photoelectrocatalysis, not only degrades organic compounds but also generates electrical current that can power electrochemical reactions to further enhance the degradation process.

“Photoelectrocatalysis surpasses other ways of reducing organic compounds in wastewater because it enables a more efficient electron transfer and can selectively target particular organic pollutants,” notes Banat. “Our gold nanoparticles exhibited remarkable catalytic efficiency and activity in reducing 4-nitrophenol under UV light irradiation.”

Banat’s team also discovered that by using the olive leaf extract, scientists could manipulate the size, shape and other properties of the gold nanoparticles. “This is pretty exciting. It means we could produce nanoparticles with adjustable properties for various applications in biomedical, catalytic and sensing fields,” Banat says. “We will certainly be pursuing our research and exploring the full potential of this green synthesis method.”

NENOV/ MOMENT/ GETTY IMAGES

More in the wastewater research pipeline

Ongoing projects related to wastewater treatment at Khalifa University include the optimization of membrane bioreactor systems to remove organic and inorganic pollutants. The research is focused on investigating the effects of different operational parameters, such as hydraulic retention time and sludge retention time, on removal efficiencies.

Researchers are also exploring the use of electrochemical oxidation for treating both industrial and municipal wastewater, and developing technologies to recover valuable nutrients such as nitrogen and phosphorus.

Syed, S.S. et al. Rapid biosynthesis and characterization of metallic gold nanoparticles by olea europea and their potential application in photoelectrocatalytic reduction of 4-nitrophenol. *Environmental Research* (2023).

Innovative membrane revolutionizes cleanup of wastewater

A novel method of removing a toxic pollutant from oil and gas wastewater could help secure a stable water supply in arid, oil-producing regions.

PHOTOTREAT/ ISTOCK / GETTY IMAGES PLUS

Oil extraction produces more than just oil. Energy companies pump large quantities of water into wells to coax petroleum from the ground, resulting in large volumes of wastewater laden with contaminants. A notable contaminant is phenol, which has been linked to organ damage in laboratory animals. Conventional water treatment methods either do not work on the toxic organic compound, or they are too expensive or energy intensive.

In the United Arab Emirates and other arid oil-producing regions, reusing this wastewater is of utmost importance to ensure a stable water supply. "This is a very dry place," says Emad Alhseinat, a chemical engineer at Khalifa University. "We don't have much water. But we have a huge amount of wastewater. Being able to use it is important for the stability of our water supply."

Building on their expertise in material and membrane science at Khalifa University, Alhseinat, in collaboration with chemist Dinesh Shetty and a research team including postdocs Jisha Kuttiani Ali and Abdul Khayum Mohammed, embarked on a quest to tackle the problem. Collaborating with researchers from Nottingham Trent University in the UK and New York University-Abu Dhabi, they discovered that, by using two materials that hadn't been combined for phenol removal before, they were able to create a low-cost solution. Their membrane, created by mixing a small amount of covalent organic framework (COF) with cellulose acetate, an affordable biodegradable polymer, had the right structure to trap phenol while allowing water molecules to pass through. Remarkably, the membrane removed 80% of the contaminant.

Shetty came up with the overall COF design, with inputs from Mohammed and Ali. Alhseinat and Ali fabricated and tested the COF-cellulose acetate membrane and performed the phenol removal. They collaborated with Nottingham Trent University on the structural simulation of the COF.

The postdocs played a crucial role in the breakthrough, says Shetty. "Khalifa University is one of the top universities in the region, and we are attracting good postdocs from around the world," he says. "For me, the most satisfactory experience was mentoring these next-generation scientists."

Alhseinat, who first joined KU as a researcher and is now an associate professor, credits the university's considerable resources for making the work, which was published in *Chemical Engineering Journal*, possible. "To succeed as a researcher and professor, you need very good research facilities, and Khalifa has just that," he says.

"There are state-of-the-art instruments, a great community, and we have very good advisors here. They are outstanding in their fields."

Mohammed, A., Ali, J. Kuzhimully, M. Addicoat, M.A., Varghese, S. Baias, M., Alhseinat, E & Shetty, D. The fragmented 3D-covalent organic framework in cellulose acetate membrane for efficient phenol removal. *Chemical Engineering Journal* **466**, 2023.

SCIENTIFIC DEFINITIONS AND FACTS

Freeze desalination

is a new low-energy desalination technology where salt crystals are removed by partially freezing the water which then solidifies, leaving the salt crystals behind in a highly saline brine. The separated ice is washed before being melted, producing fresh water at low cost.

Not all emission reduction goals should be created equally

With only three countries in the region on track for the °1.5C global warming goals, a new study suggests it may be more realistic–and fairer–to take socioeconomic differences into account.

MIKEDOT/ ISTOCK / GETTY IMAGES PLUS

Did you know?

The 2015 Paris Agreement targets keeping the global temperature rise below a 2°C increase relative to pre-industrial levels.

Climate change mitigation should have never been higher up on the regional agenda, with COP27 being hosted in Egypt in 2022, and COP28 in the United Arab Emirates this year—or so one would imagine. A new study by Khalifa University Professor of Practice and Senior Vice President for Research and Development Steve Griffiths and collaborators from the Cyprus Institute indicates that with only five exceptions, all 17 countries in the Eastern Mediterranean and Middle Eastern (EMME) region have not set greenhouse gas emission reduction strategies that align with ranges the researchers consider equitable for keeping the global temperature rise below a 2°C increase relative to pre-industrial levels, which is a target laid out in the 2015 Paris Agreement.

Although the EMME region as a collective would need to drop its emissions by nearly 50% by 2030 to be in line with the more ambitious 1.5°C global warming scenario, the study, published in Climate Policy, indicates that it is crucial to look beyond sheer emissions reduction numbers. The research advocates that when setting climate change targets and strategies, policymakers should take into account factors like the socioeconomic and political context of each country, as well as historical emissions.

"Countries regionally and globally have very different levels of wealth, very different demographics and very different levels of maturity in terms of what they have been doing to try and deal with carbon emissions," says Griffiths.

The authors argue that approaches that combine equity principles of capability, responsibility and equality should be considered in order to identify those that are both realistic and fair. This means that some countries experiencing instability or that are in fragile situations socially, economically or politically, like Syria, may not be able to take immediate climate change mitigation actions aligned with their historical emissions. Such countries might be allowed to increase their emissions in the short run to be able to improve their economies and societies before they are asked to reduce their emissions.

"Some countries, particularly those with high emissions and who are wealthy, have more of a burden," Griffiths adds.

The study advocates for focusing carbon emissions targets and strategies primarily on the equity principles of responsibility and capability. Because oil-reliant economies like the Gulf countries may not be able to achieve decarbonization targets by 2030 without heavily affecting their economies, the authors suggest that these countries take leading roles in implementing emissions mitigation approaches, such as Circular Carbon Economy (CCE) or Extended Producer Responsibility (EPR) principles. CCE and EPR promote carbon removal as means of achieving net-zero carbon emissions rather than eliminating emissions altogether.

Griffiths explains that Saudi Arabia and the UAE are already taking initiative on the CCE and EPR fronts and are well poised to be regional leaders on the approaches. "Many countries will not be able to pick up the costs associated with developing carbon capture, removal, utilization and storage technologies that can benefit all countries regionally and globally. The Gulf countries, however, can and are developing these technologies," he notes.

The EMME region includes Bahrain, Cyprus, Egypt, Greece, Iran, Iraq, Israel, Jordan, Kuwait, Lebanon, Oman, Palestine, Qatar, Saudi Arabia, Syria, Turkey and the UAE. These countries, Griffiths explains, present a diverse set of different socioeconomic situations and climate contexts. "I believe that there is a need to look at the whole world together when you are looking into decarbonization requirements. Some countries will lead the effort because of their current circumstances. Considering the EMME region a collective allows us to partition commitment timelines most suited to individual national situations," explains Griffiths.

Out of the 17 countries, only Greece, Iran, Israel, Jordan and the UAE currently have Nationally Determined Contributions (NDCs) with 2030 carbon emissions targets that the researchers consider in line with equitable ranges for achieving the Paris Agreement 2°C goal. Even fewer—three, including the UAE—fall in line with ranges that encompass the 1.5°C goal. By contrast, Egypt, Iraq, Kuwait, Oman, Palestine and Turkey have 2030 NDC carbon emissions targets that actually point to an increase in emission levels compared to 2016. None of the countries studied have proposed a strategy to reduce 2030 carbon emissions by more than half relative to 2019 levels. It is ultimately this level of ambition, however, that may be required to meet the very challenging Paris Agreement 1.5°C goal.

Yiakoumi, D. et al. Sharing the decarbonisation effort: Getting Eastern Mediterranean and Middle East countries on the road to global carbon neutrality. Climate Policy (2023).

A bio-based solution to quickly eliminate single-use plastics altogether

A concerted effort to speed up development of bio-based packaging materials could soon make single-use plastics a thing of the past.

Synthetic materials remain major contributors to global pollution despite increasing recycling rates. Non-biodegradable plastics, such as single-use plastics, release harmful endocrine disruptors and tiny particles that accumulate in the environment, pushing pollution to near-critical levels. Alternative bio-based compounds produced from renewable and green sources such as food waste could be a sustainable alternative, and would seamlessly integrate into the biosphere, minimizing the effect of common plastic pollutants.

An international team led by researchers at Khalifa University has proposed guidelines that could help accelerate the development of bio-based materials into scalable packaging materials and eliminate single-use plastics typically used for food packaging.

"Using more bio-based building blocks can increase the profitability of growing biomass and promote a greener world," says chemical engineer and lead author Blaise Tardy, from KU's Research and Innovation Center on CO2 and H2 (RICH).

ANDRIY ONUFRIYENKO/ MOMENT/ GETTY IMAGES

"Using more bio-based building blocks can increase the profitability of growing biomass and promote a greener world."

—Blaise Tardy, Research and Innovation Center on CO2 and H2, Khalifa University.

Tardy and collaborators suggest that the slow technology transfer between industry and academia is a result of the disconnect between publicly funded research and research funded by industry. They noticed that team leads from industry did not read the scientific literature but relied on unpublished internal findings. Conversely, most scientific publications involved only academics, and their real-world impact waned over the years.

To remedy this disconnect, the researchers have suggested that scientists follow specific targets when it comes to isolating and transforming bio-based building blocks into scalable packaging materials, set through discussions with companies, and government support. Scientists should also adopt a more modern approach to industry interactions, such as open innovation schemes; as current translation schemes are neither benefiting universities nor society.

"The way Khalifa University interacts with industry is in this direction," Tardy says.

Now the KU team is studying ultrasmall natural fibers obtained by breaking down cellulose, the Earth's most abundant biopolymer. In addition to being biodegradable, these nanofibers, or fibrillated cellulose, present interesting mechanical, optical and thermal properties, making them attractive for numerous applications, including food packaging.

According to Tardy, industry has made early developments on these fibers but problems have emerged, slowing wider implementation of industrial scale-up. "Everyone is publishing on this topic," he says, "but you cannot always use the data between publications. For example, there are many reports focused on the nano-sized fibers from different types of banana peel, but the data is not benchmarked. Therefore, industry cannot know which findings are improving the state of the art."

The researchers are currently evaluating various sources of cellulose to define benchmarks. The team is also assessing the potential of several green packaging solutions. "Much of our focus is on processing regional biomass to obtain high-quality building blocks for sustainable materials, a budding practice in arid areas," Tardy concludes.

Tardy, B.L., Richardson, J.J., Greca, L.G., Guo, J., Bras, J. & Rojas, O.J. Advancing bio-based materials for sustainable solutions to food packaging. *Nature Sustainability* **6**, 360–367 (2023).

LILACHECK-PHOTOGRAPHY/ MOMENT UNRELEASED/ GETTY IMAGES

Forecasting air quality for cleaner skies across the United Arab Emirates

How Khalifa University is monitoring air quality across the country to mitigate climate change.

Air pollution is a global problem, and when air quality drops to unhealthy levels, it affects both the environment and human health. Emitted mainly from the combustion of fossil fuels, nitrogen dioxide (NO_2) is one of the main air pollutants and contributes to the formation of ground-level ozone, smog and acid rain.

At Khalifa University's Department of Electrical Engineering and Computer Science, Zeyar Aung and PhD candidate Aishah Al Yammahi have worked on mathematical models that analyze NO_2 data to uncover patterns and forecast future air pollution levels in the United Arab Emirates. Their published results and current research projects are addressing United Nations' Sustainable Development Goals, shaping our understanding of environmental dynamics, and paving the way for pollution mitigation strategies.

Extracting meaningful patterns from weather stations across the country

In a recent study, Aung and Al Yammahi analyzed NO_2 data from 14 weather stations, located in Abu Dhabi, Al Dhafra, Al Ain and rural areas of the UAE. The data spanned a two-year period, from 2019 to 2020, and was made available by the Environment Agency Abu Dhabi (EAD). Publishing their findings in *Scientific Reports*, Aung and Al Yammahi's results showed the effect of seasons and human activities to the concentration level of NO_2. The two researchers used a mathematical tool, known as wavelet transform, to identify periodic patterns present in the data.

Similar to a magnifying glass that can zoom in or out on the data, the models allowed researchers to see both the big picture and the fine details. They could reveal both geographic and seasonal differences, as well as the effect of the COVID-19 lockdown between April 2020 and July 2020, when schools and universities were closed and employees were predominantly working from home.

For example, NO_2 was more highly concentrated during the winter season, probably due to decreased sunlight and lower temperatures, between December 2019 and February 2020. The highest NO_2 levels were detected in downtown Abu Dhabi, while desert and urban areas showed the lowest concentrations.

The lockdown had a positive effect on air pollution in Emirati cities. Stations in the urban areas of Abu Dhabi city, Al Dhafra and Al Ain all showed a reduction in NO_2 during the lockdown. On the other hand, NO_2 concentrations during the same period in the desert areas of Liwa and Al Quaa were unaffected.

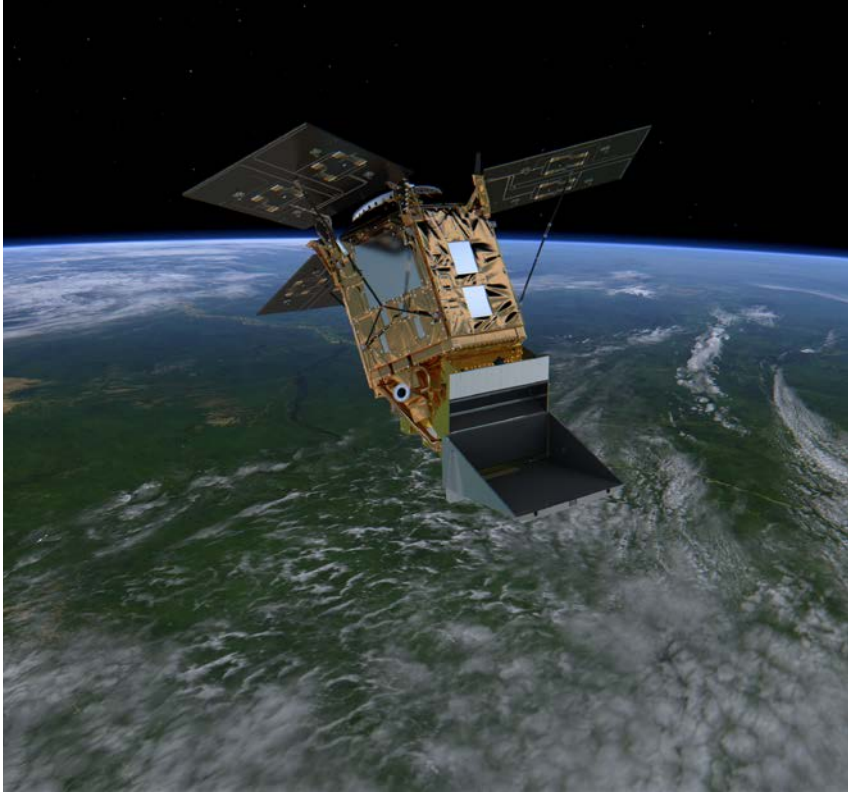
The study showed that the level of NO_2 varied in a repeating pattern or cycle and lasted from a few days up to 16 days in most regions. An exception was the area of Al Mafraq in Abu Dhabi where the pre-pandemic periodicity of NO_2 was much longer, between 64 to 128 days. The exact reason for this pattern may depend on various factors that affect the release and dispersion of NO_2 in the air, such as atmospheric conditions, seasonal changes and human activities. By studying the periodicity of pollutants, scientists can gain insights into their behavior, understand their sources and impacts, and advise strategies for pollution control and mitigation.

"The results give us a much better understanding of the seasonality and periodicity of NO_2 across the urban and rural areas in the United Arab Emirates. This study along with similar studies on greenhouse gases conducted at Khalifa University and other research institutions provide valuable results to inform policy makers," says Aung, who teaches at the Department of Electrical Engineering and Computer Science.

"We focused on NO_2 as a case study. However, the same methods and types of analysis could be applied to other types of air polluting gases," explains Al Yammahi.

Forecasting air pollution with statistics and machine learning

Beyond analyzing NO_2 data from the past, Aung and Al Yammahi have also applied two statistical models and two machine learning models to forecast future NO_2 concentration levels. They trained the models with the data from January 2019 to November 2020, and then used the trained models to predict the NO_2 concentration values for December 2020. The researchers compared the predicted data with the measurements from the weather station to determine the most effective forecasting methods.



ESA/ATG MEDIALAB

"This study along with similar studies on greenhouse gases conducted at Khalifa University and other research institutions provide valuable results to inform policy makers."

There are two basic modes of forecasting: open-loop and closed-loop. In the open loop, 700 days (1 January 2019 to 30 November 2020) were used to train the models and predict the NO_2 levels for the following day (1 December 2020). Subsequently, the actual data from 701 days (1 January 2019 to 1 December 2020) were used to train and forecast for the following day (2 December 2020).

On the other hand, closed-loop forecasting utilizes the data from 700 days to make predictions ranging from 1-31 days ahead. Typically, the closed-loop architecture is faster but less accurate compared to the open-loop architecture. In this study, published in the journal Heliyon, the machine learning models and the open-loop method demonstrated better accuracy, closely predicting the NO_2 values.

"We achieved accuracies ranging from very good to acceptable in all the 14 locations included in our study," adds Al Yammahi.

A glimpse at the future: monitoring air pollution from the sand to the sky

Beyond the data on air pollution coming from weather stations, the team is keen on analyzing the concentration of NO_2 present in its natural trappers, such as sand. Sand acts as a sink, where pollutants can accumulate over time. "Environmental samples can reveal the historical concentration levels of NO_2 and other pollutants, whereas the ground stations typically measure atmospheric NO_2 level at a particular time point," explains Aung.

Furthermore, satellite-based instruments offer another way to monitor NO_2 concentrations over large are-

as, including remote or inaccessible regions. For example, the European Space Agency (ESA) launched the SENTINEL-5 satellite in 2021. One of the objectives of this satellite is to measure NO_2 as well as ozone sulphur dioxide and other pollutants based on their unique ways of absorbing and scattering light of visible and non-visible wavelengths.

"We are currently exploring the combination of satellite data from SENTINEL-5 with ground-based measurements and various modelling techniques to assess air quality, monitor pollution sources and evaluate the effectiveness of pollution control measures," says Aung.

The study of air quality and climate change remains at the forefront of Khalifa University's strategic priorities. This commitment is evident through the recent signing of a Memorandum of Understanding between the Environment Agency – Abu Dhabi (EAD), Khalifa University, and seven other esteemed universities in the United Arab Emirates. By joining forces, the country is poised to make significant contributions to understanding and mitigating the impact of air pollution and climate change in the region.

1. Al Yammahi, A. & Aung, Z. A study of nitrogen dioxide (NO2) periodicity over the United Arab Emirates using wavelet analysis. *Scientific Reports* **12.1** (2022).
2. Al Yammahi, A. & Aung, Z. Forecasting the concentration of NO2 using statistical and machine learning methods: A case study in the UAE. *Heliyon* **9.2** (2023).

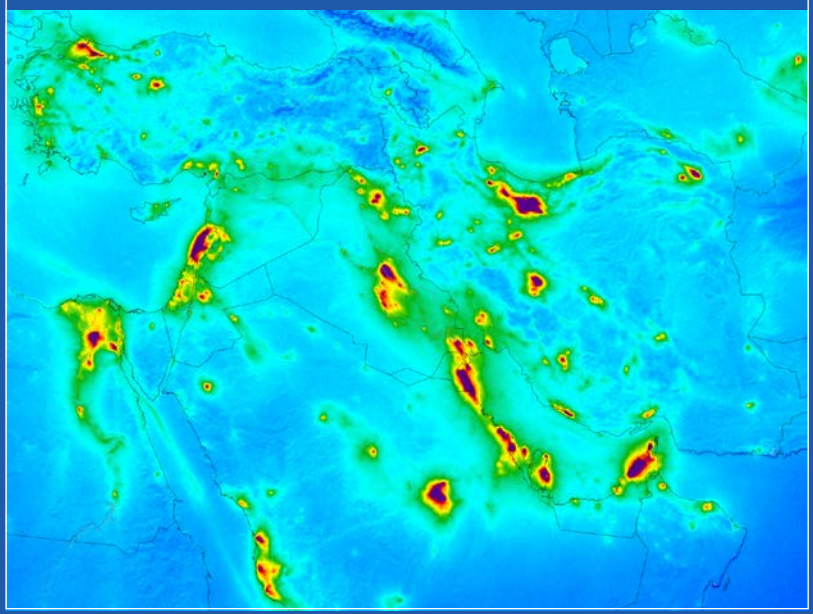
Understanding the lifespan of NO_2 in the air

Unravelling the lifespan of NO_2 in the atmosphere is a complex task: it can vary from a few hours to days and depends on several factors, including sunlight intensity and the presence of other air pollutants. When hydrocarbons in fossil fuels react with air in combustion engines, they produce mainly nitric oxide (NO) and some NO_2.

Sunlight can trigger the conversion of NO_2 to NO, resulting in the production of ground-level ozone as a side pollutant. Other air pollutants can play a role in the conversion of NO to NO_2, and NO_2 can react with other substances to produce respiratory irritants, such as nitric acid, particulate matters and peroxyacyl nitrates.

An AI-based platform to monitor and predict air quality

Khalifa University of Science and Technology in collaboration with the UAE's Ministry of Climate Change and Environment (MOCCAE) has created an Artificial Intelligence (AI) platform that displays real-time air quality readings based on satellite data. The tool can also predict the UAE's air quality and the concentration of dust and particulate matters with a diameter of less than 2.5 microns (PM 2.5) for up to three days in advance. The tool can be found on the MOCCAE website at https://ai-for-sdgs.academy/case/274.



ESA/ MODIFIED COPERNICUS DATA (2018), PROCESSED BY KNMI

Innovative clean energy solutions to address carbon dioxide and hydrogen challenges

A multipronged strategy for carbon capture and conversion as well as hydrogen production is set to provide sustainable energy solutions.

Sustainable energy sources are critical for both improving quality of life and fostering economic growth. However, fossil fuels dominate current energy production, causing substantial CO2 and greenhouse gas emissions that harm the environment. Solutions to this fossil fuel dependency require a holistic approach encompassing economic, security and environmental considerations.

To address these challenges, Khalifa University has adopted a multipronged strategy encompassing carbon capture and utilization as well as H2 production. The first technology involves collecting produced CO2 before its release into the atmosphere and either storing it in geologic formations or transforming it into useful products or materials. Hydrogen, an energy vector that can be derived from low-carbon sources and serve as a clean fuel or feedstock, is equally important.

However, high cost and inadequate infrastructure have prevented these technologies from reaching their full potential.

Now, thanks to cutting-edge research and innovation at KU's Research and Innovation Center on CO2 and H2 (RICH), these issues are being addressed.

A mission to decarbonize

Under the directorship of Lourdes Vega, Khalifa University established RICH in 2019 to catalyze the UAE's energy transition efforts.

"We saw the opportunity to create this unique center after the Petroleum Institute, Masdar Institute, and Khalifa University of Science of Technology and Research merged into the current Khalifa University in 2017, bringing together experts in the fields of CO2 and hydrogen from the three institutions," Vega says. The center is expected to generate knowledge and applications in the fields of CO2, hydrogen and clean energy.

Research at RICH involves a multidisciplinary strategy combining modelling and experimental methods to develop novel materials and technologies for carbon capture and utilization, as well as H2 production, storage and distribution. It covers all areas ranging from materials chemistry, sustainable fuels, membranes, process modelling and optimization, biochemistry to fuel cells and life cycle assessment.

"Fundamental science is key for decarbonization and sustainability because [that's how we make] technological breakthroughs, but we also need to put our determination and imagination into finding the best ways to apply it, so that the planet and society benefit from this knowledge. Hence, anyone can be part of the game," explains Vega, who believes in leading by example.

Ahmed Al Hajaj, a member of RICH, focuses on promoting and expediting the advancement of decarbonization technologies. He has devised an integrative approach to design high-performance CO2

Researchers explore innovative ways to generate materials with enhanced CO2 capture efficiency.

capture materials. His team seamlessly blends experimental efforts, which generate vital data and material insights, with molecular simulations and process models.

The holistic approach provides the means to tailor material design and development stages based on an understanding of underlying physical phenomena. The approach also fast-tracks the maturation of novel materials and processes, he explains, allowing researchers to identify trade-offs associated with materials and overcome issues that previously hindered large-scale technologies, such as the ill-fated commercial-scale carbon capture and sequestration projects.

"Fundamental science is key for decarbonization and sustainability because [that's how we make] technological breakthroughs."

Toward optimal carbon capture

RICH researchers have explored various innovative approaches to generate materials with enhanced CO2 capture efficiency. They have modified the surface of graphene oxide—a high-surface-area derivative of the single-layered carbon-based material graphene that can adsorb gas molecules—using UV light. The resulting graphene oxide foam captured 30 times more CO2 and pre-

KHALIFA UNIVERSITY

sented seven times greater capacity under certain conditions compared to its precursor.

They have also produced activated carbon-based materials from nontraditional sources, such as waste from date seeds. Additionally, they developed hybrid materials, such as graphene oxide and highly ordered porous compounds called metal organic frameworks. These hybrids exhibit higher capture efficiency than their individual precursors.

Another approach conceived by Ludovic Dumée, a RICH member and expert in molecular separation and selective resource recovery, focuses on extracting CO2 present at low concentration in air and sea water. While challenging, this approach could help reduce emissions and generate CO2 on demand.

Dumée's team is working on reducing the energy footprint of technologies involved in extracting CO2 from dilute streams and, in this case, engineering scalable nanostructured materials that are more selective and easier to regenerate.

Aligning with global players

One of RICH's main goals is to promote knowledge exchange, technology transfer, and awareness of CO2 and H2-related technologies globally. It aims at educating scientists and engineers, fostering collaboration with industry, and contributing to a sustainable energy future.

To enhance the center's visibility, members organize events and participate in international conferences, such as the 15th International Conference on Greenhouse Gas Control Technologies, the 13th Asia-Pacific Conference on Combustion, and the 16th International Conference on Properties and Phase Equilibria for Process and Product Design.

"Faculty members at RICH are actively looking for collaborations from academia and industry, as this is part of our DNA, and the only way to be at the forefront in our areas of expertise," Vega says.

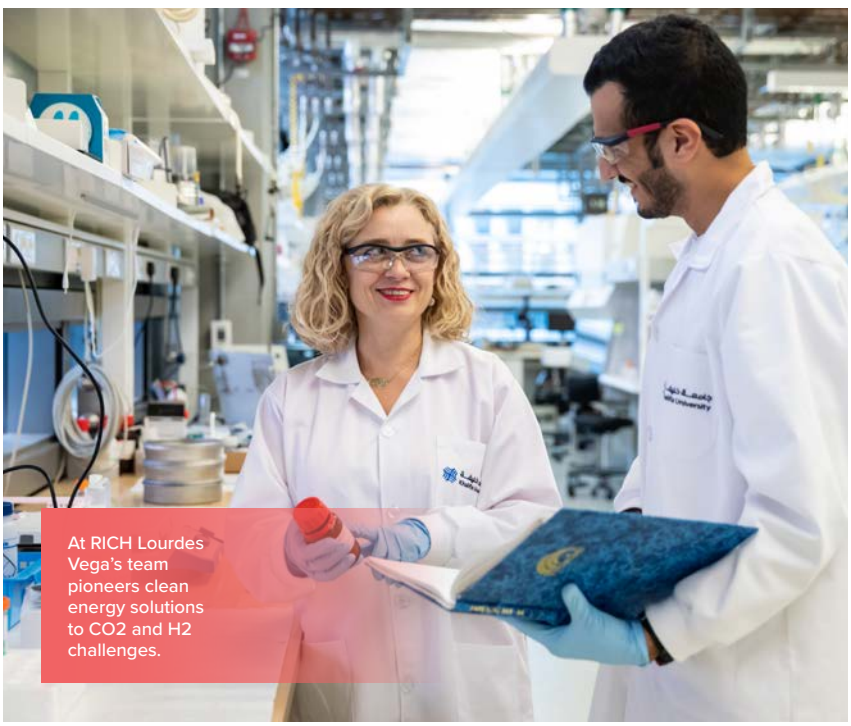
Since the inception of the center, members have established academic collaborations with key players from around the world, with whom they exchange students and visitors, co-advise graduate students, and publish together. They also closely collaborate with national and international companies, agencies and the government.

RICH, for instance, is working with Emirates Steel Arkan and the cement company AlJazeera Factory on a project that involves reacting CO2 with waste from the steel factory to produce lightweight, precast, foam concrete building materials suitable for manufacturing block-like masonry units.

Another strategic collaboration with the energy group Advanced Turbine Development/Creative Power Solutions (ATD/CPS) focuses on hydrogen utilization and sustainable fuels for combustion. The partnership, managed by Dimitri Kyritsis who oversees research on hydrogen transportation and utilization, has led to the creation of a high-pressure combustion research facility.

The facility is provided by ATD/CPS and Atlas Electronik and will make it possible to test flexible fuels derived from hydrogen, natural gas- and ammonia-based hydrogen blends, and synthetic fuels developed inhouse under industrial conditions.

"Our mission is to advance clean technologies as much as we can, and we are eager to put our efforts in this direction with as many partners as possible," Vega says.



At RICH Lourdes Vega's team pioneers clean energy solutions to CO2 and H2 challenges.

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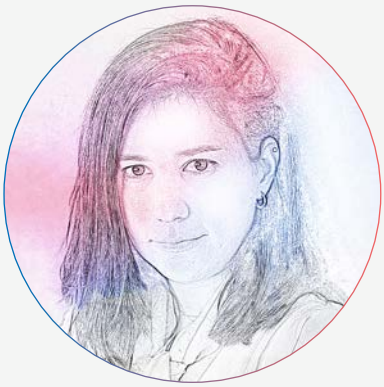
AT THE CROSSROADS OF BIOLOGY AND ELECTRONICS



Anna-Maria Pappa, Assistant Professor, Department of Biomedical Engineering, Khalifa University of Science and Technology.

Anna-Maria Pappa, assistant Professor at the Department of Biomedical Engineering at Khalifa University and a visiting scholar at the University of Cambridge in the UK. She moved from chemical engineering to healthcare diagnostics via nanotechnology, and now runs a research group at Khalifa University..

How did you find your way into bioelectronics research?

Serendipity! I was doing my master's degree in Greece, when I met my future PhD adviser Roisin Owens, during her sabbatical as a visiting professor. I was impressed by her approach to science. I asked if she had any available positions in her group, and luckily, she did.

I stress to students that choosing a PhD program largely revolves around the adviser. Of course, if they have a shared area of scientific interest, even better. In my case, I was not interested in bioelectronics at the time, but I have developed a deep passion for it and my PhD years in France were the best in my life.

What is the current focus of your research?

Since establishing my own group here at KU, we've divided our bioelectronics interests into two primary areas: wearable biosensors and cell membranes on chip. Although the final applications seem different, the common denominator is improving the interface between the biotic (biological) and the abiotic (electronic) components.

What are the challenges of this type of work?

We face a significant contrast between the soft communication through ions that takes place in biology and the hard, electron-based communication used by conventional electronics. This communication mismatch can significantly hinder the efficacy of bioelectronic devices through signal loss, in addition to compromising the functionality of the biological components.

To address this, we use conducting polymers, also known as plastic electronics. They exhibit properties that resemble the in vivo environment of cells and proteins and are biocompatible. Moreover, they have practical advantages such as cost-effectiveness and being easy to process by printing. I believe these materials are the future of bioelectronics.

What makes Khalifa University a good place to work?

First and foremost, I've been able to establish valuable collaborations with colleagues from complementary fields. Multidisciplinarity, which has always been integral to my research, is an approach that the university supports. Additionally, it offers great opportunities for both internal and external funding. In my two years here, I've seen a lot of initiatives aimed at strengthening research activities and promoting international collaborations.

What is your most significant achievement?

It was a great honor to get a L'OREAL UNESCO fellowship award for women in science in 2017 for my PhD activities. Also, during my postdoc studies at the University of Cambridge, I was named among Massachusetts Institute of Technology's list of innovators under 35. This recognition coincided with the day I gave birth to my son, which was the biggest highlight of all!

What breakthroughs in bioelectronics are you hoping to witness?

A substantial breakthrough has already been achieved with the development of implantable bioelectronic devices that stimulate the spinal cord, restoring mobility after paralysis. This was pioneered by Stephanie Lacour and Grégoire Courtin at EPFL. They've made remarkable progress in treating paralysis. In the future, the possibilities are vast, including: edible electronic pills that map specific parts of our body and deliver drugs on demand; wearable sensors that continuously monitor our health; neurovegetative-disorder treatments using electrical stimulation; and so many others.

Jabal Hafeet mountain lies on the border between the United Arab Emirates and Oman.

Decoding Arabian landforms reveals more than geological history

An innovative approach to determining the forces that have shaped the southeast Arabian Peninsula over the past 20 million years could inform the success of future carbon dioxide storage operations.

LEONID ANDRONOV / ALAMY STOCK PHOTO

Many of the Earth's most notable geological features formed in the past 66 million years, a time known as the Cenozoic era. Understanding how these physical formations resulted from the planet's shifting tectonic plates continues to inform earthquake prediction and the search for oil and gas, but may take on a new climate change-related significance in identifying optimal sites for carbon dioxide storage and nuclear waste containment.

Francesco Arboit, from the Department of Earth Sciences at Khalifa University, in collaboration with colleagues from Trinity College Dublin in Ireland, is studying the Cenozoic compression—the collision of the northward-moving Arabian Plate with the Eurasian Plate as it moves north-northeast. This geological compression continues to shape the Arabian Peninsula, giving rise to a number of features such as the Zagros Mountains in Iran, Iraq and Turkey, the Hajar Mountains in Oman and the United Arab Emirates, and the Southeast Arabian Foreland Basin that lies between them.

Several tectonic mechanisms have been proposed to explain how the foreland basin formed. Arboit points out that one tangible manifestation of these deformational effects can be seen at the surface of the Southeast Arabian Foreland Basin just outside the city of Al Ain. Here, the compressional forces have folded the rock layers upwards. The Jabal Hafeet anticline, composed of carbonate rock, stretches approximately 26 kilometers in length and spans five kilometers in width.

"We used an innovative approach to determine the absolute timing of the deformation events by mixing geochemical imaging with uranium-lead dating and geochemical characterization of the cements that form in the rock fractures and faults," explains Arboit.

By analyzing 500 samples extracted from several separate locations throughout the anticline, the team unearthed a compelling timeline of events. The researchers concluded that the basin had been experiencing a steady east-to-west push of the Makran compression onto the Arabian Block, which has been evident in the Southeast Arabian Foreland Basin for about 20 million years. The movement has developed into three distinct phases of brittle deformation occurring around 20, eight and two million years ago, leading to the formation of the Jabal Hafeet mountain.

The team also identified carbonate veins within the basin, which shed light on the presence of complex hydrocarbons, suggesting a history of fluid flow from deeper rock formations to the surface during the Cenozoic period.

"While this research didn't directly focus on carbon dioxide storage sites, the rocks we investigated yield key information for this purpose," says Arboit. "So, it is of crucial importance to understand when and how these rocks were deformed to maximize the success of carbon dioxide storage operations."

Arboit, F., Drost, K., Decarlis, A., Chew, D., Hennhoefer, D. & Ceriani, A. The influence of Cenozoic Eurasia-Arabia convergence on the Southeast Arabian Foreland Basin: new geochronological and geochemical constraints from syn-kinematic carbonate mineralization. *Scientific Reports* **13**, 4387 (2023).

A greener route to metal-organic frameworks

A simple, eco-friendly method produces highly ordered copper-based metal organic frameworks.

Khalifa University has developed a user-friendly method that generates high-performance porous materials known as 2D conjugated metal organic frameworks without requiring solvents. The new approach could offer scalable and environmentally conscious solutions to many issues related to energy storage, optoelectronics and electrocatalysis.

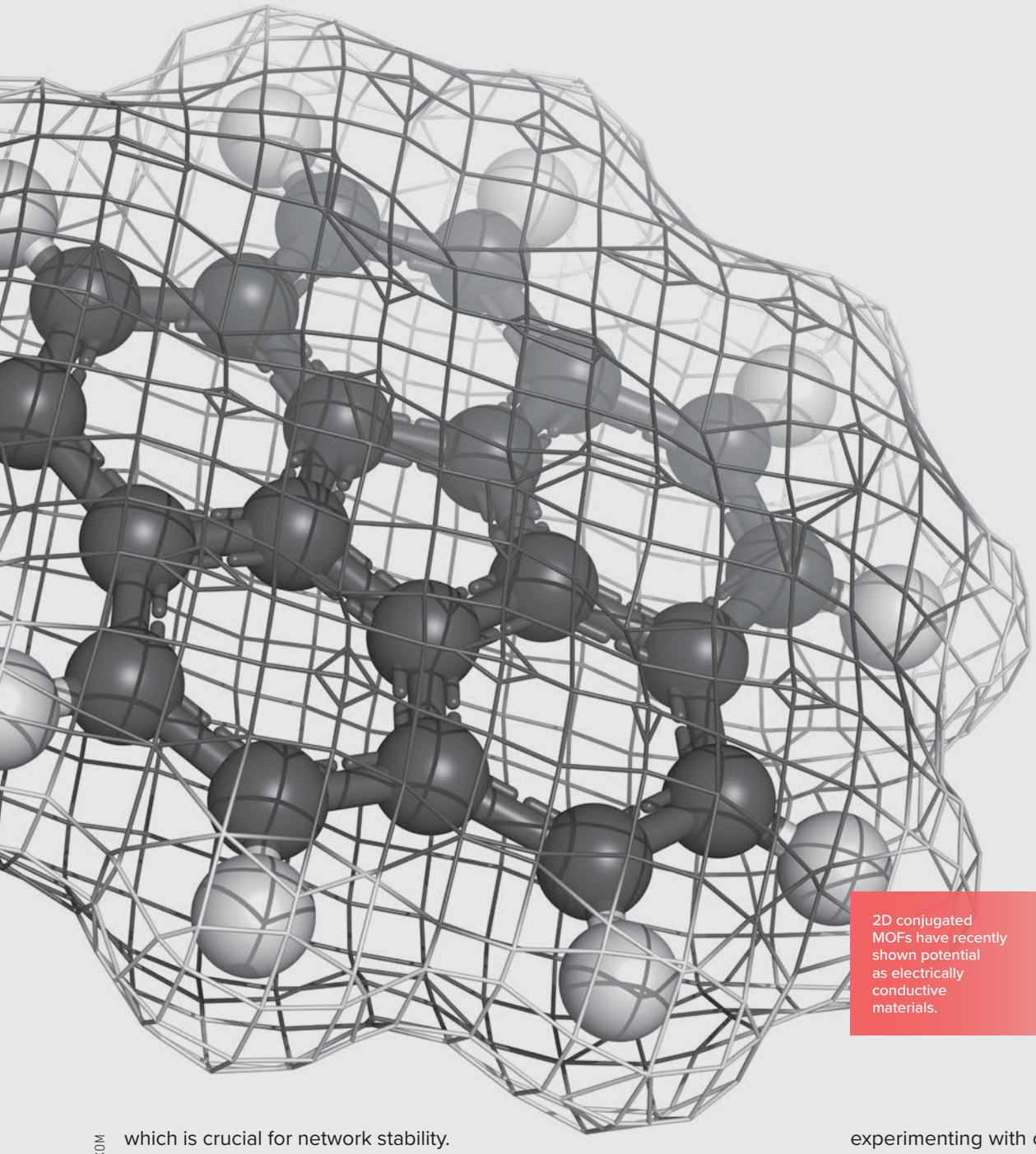
Two-dimensional conjugated metal organic frameworks have recently shown potential as electrically conductive materials because of their outstanding intrinsic electrical and optical properties. Key to these physical properties is their well-defined molecular architecture, which involves inorganic nodes connected to organic building blocks bearing pre-oriented functional groups for metal coordination. The linkers consist of benzene-derived backbones that promote 2D electron transport via π-conjugation in the resulting networks.

Despite their potential applications, few approaches have been developed to generate these networks. This is because existing organic backbones, which consist of expensive polycyclic aromatic hydrocarbons, are costly and difficult to synthesize. Only a handful of functional groups, such as carboxylic acids, amines, and thiols, have been explored for metal coordination.

Now, an international team led by Dinesh Shetty from the university's Center for Catalysis and Separation has devised an eco-friendly method that readily produces 2D conjugated frameworks by combining linkers called salicylaldehydes with copper ions.

Salicylaldehyde linkers, which contain the oxygen-based functional groups aldehyde and hydroxyl next to each other, are typically used to fabricate covalently bound organic networks. In contrast, the researchers decided to investigate its ability to create metal organic frameworks. They chose a salicylaldehyde linker comprising a benzene core bearing three aldehyde–hydroxyl pairs. Each aldehyde–hydroxyl pair can bind to one metal by forming two bonds,

"Having these groups next to each other helps provide a better coordination and makes the array of ligands directly attached to the metal ions, or coordination sphere, complete."



STUDIOMOLEKUUL/ SHUTTERSTOCK.COM

2D conjugated MOFs have recently shown potential as electrically conductive materials.

which is crucial for network stability.

"Having these groups next to each other helps provide a better coordination and makes the array of ligands directly attached to the metal ions, or coordination sphere, complete," Shetty says. "Imagine yourself holding a metal atom with both hands instead of one. Two hands give much stronger structure, and the metal cannot leach out," he explains.

The researchers added a commercially available salicylaldehyde powder to several copper salts in a mortar, ground the powders together using a pestle without catalyst or organic solvent, and heated the solid mixtures to 90°C for five hours.

The resulting networks showed good crystallinity and excellent stability. In a proof-of-concept experiment, these networks exhibited promising electrical conductivity when deposited on copper foil.

The team is now evaluating various salicylaldehyde-based networks experimenting with other metal ions and expanding the aromatic component of the linkers to optimize the stability and electrical conductivity of their system.

Mohammed, A.K., Pena-Sánchez, P., Pandikassala, A., Gaber, S., AlKhoori, A.A., Skorjanc, T., Polychronopoulou, K., Kurungot, S., Gándara, F. & Shetty, D. Salicylaldehydate coordinated two-dimensional-conjugated metal-organic frameworks. *Chemical Communications* **59**, 2608–2611 (2023).

Igniting a vibrant ecosystem of innovation in 2D materials

The Research & Innovation Center for Graphene and 2D Materials (RIC2D) at Khalifa University solves the local challenges of developing and deploying innovative materials, while fostering worldwide collaborative academic and industrial partnerships.

For the past two decades, graphene has captivated scientists with its exceptional properties, including high thermal and electrical conductivity, large surface area, remarkable strength, and flexibility. Understanding graphene has underpinned the discovery of an extensive family of 2D materials, finding application across numerous sectors.

Launched in April 2022, the Research & Innovation Center for Graphene and 2D Materials (RIC2D) is a major innovation hub at Khalifa University, focused on the development and commercialization of technologies that benefit the United Arab Emirates and beyond.

Committed to local impact

RIC2D's research focuses on applications relevant to the UAE including water purification, production of lightweight composites and material innovations in aerospace, energy and healthcare. For example, integrating graphene into the water-membrane technologies used in water treatment can reduce the energy consumption and cost of the desalination process. This is a significant step that would help the UAE, which grapples with increasing water scarcity.

Similar benefits could help the construction sector, which is booming in the Gulf region. Cement production generates substantial emissions of carbon dioxide, a potent greenhouse gas. Introducing graphene into the concrete mix, however, could reduce the quantity of cement required, leading to a lower carbon footprint. Graphene and other 2D materials can also be blended with copper to enhance the electrical conductivity of wires and incorporated into other components to reduce their weight.

Senior Director at RIC2D Professor Hassan Arafat is keen to emphasize the importance of conducting this work locally. "We needed to establish this research center

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This graphite is a crystalline form of carbon with its atoms arranged in a hexagonal structure.

Did you know?

Graphene can be blended with copper to enhance the electrical conductivity of wires.

here in Abu Dhabi, rather than just relying on scientific results from abroad," he explains. "Take the construction industry: the climatic conditions and needs in Europe are very different from those in the UAE, so it is important to perform this research considering the local context.

"In addition, we will identify promising startups across all universities in the UAE and provide them with space, funding and equipment."

Supporting international collaboration

In addition to its local work, RIC2D is committed to fostering collaborations to strengthen links with international partners. Student and staff exchanges, joint research projects and commercialization efforts are already underway between RIC2D and the University of Manchester's Graphene Engineering Innovation Centre (GEIC) in the UK. Looking ahead, RIC2D aims to expand its network across Europe, Asia and the United States.

A catalyst for these collaborations is the RIC2D Research and Innovation Fund, which has received collaborative research proposals from universities and companies around the world working in tandem with Khalifa University professors. "As soon as the results of this fund are announced, RIC2D will enter a new and exciting phase," says Arafat.

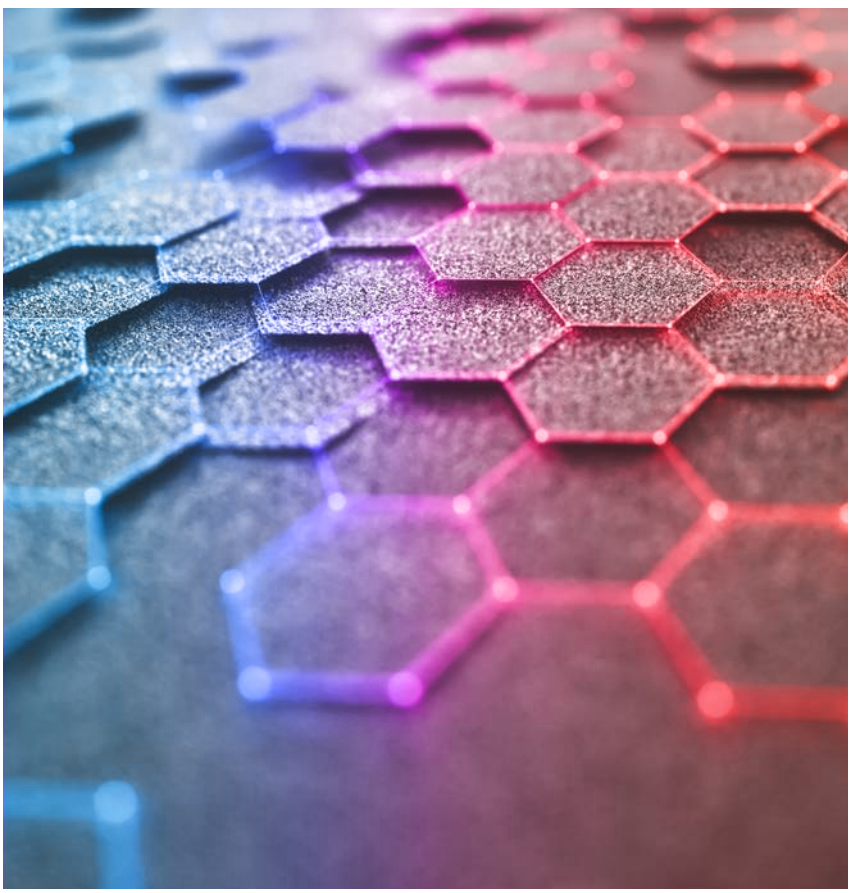
To nurture international collaborations, RIC2D hosted the first UAE-EU symposium on 2D materials: technologies and industrial potential in May 2023. The event was organized jointly by RIC2D and the Graphene Flagship, an established European consortium of hundreds of academic and industrial research groups, working on fundamental and applied research into 2D materials. The symposium was chaired by RIC2D's Arafat and the Graphene Flagship Head of Innovation Kari Hjelt.

The two-day event gave more than 140 attendees, from academia and industry in Europe and the UAE, the opportunity to share scientific results and explore topics of common interest. Nine industrial delegates from the Graphene Flagship presented projects to members of the UAE's government and private sectors at Hub71, Abu Dhabi's global tech ecosystem dedicated to fostering the growth of tech founders and startups. The event was also attended by the Mubadala Investment Company, a major sovereign wealth fund in the UAE.

> **"We needed to establish this research center here in Abu Dhabi, rather than just relying on scientific results from abroad."**

The bond between the Graphene Flagship and RIC2D was strengthened at a second joint event during September's Graphene Week 2023 in Gothenburg, Sweden; the flagships' annual event. Attendees were encouraged to delve deeper into discussions on environmental and societal challenges that can be tackled with 2D materials.

"I believe that technologies based on 2D materials are poised to make a real impact on our lives. In 2023, every single country in the world has seen the impact of climatic disasters in various manifestations. Knowing that graphene has the potential to reduce the consumption of materials and energy brings a satisfying feeling that we are contributing to a very big cause," enthuses Arafat.



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Delving into nanomaterials

RIC2D symposium speaker Rashid K. Abu Al-Rub talks to revolutionizing nanomaterials by combining 2D materials and 3D printing.

Exploring the mantra "smaller is stronger," Rashid K. Abu Al-Rub has delved into the study of nanomaterials since gaining his PhD. As Professor of Mechanical Engineering and the Director of the Advanced Digital & Additive Manufacturing Center (ADAM) at Khalifa University, Abu Al-Rub's focus lies in combining 2D materials and 3D printing, with the aim of enhancing the aerospace, defense and automotive sectors.

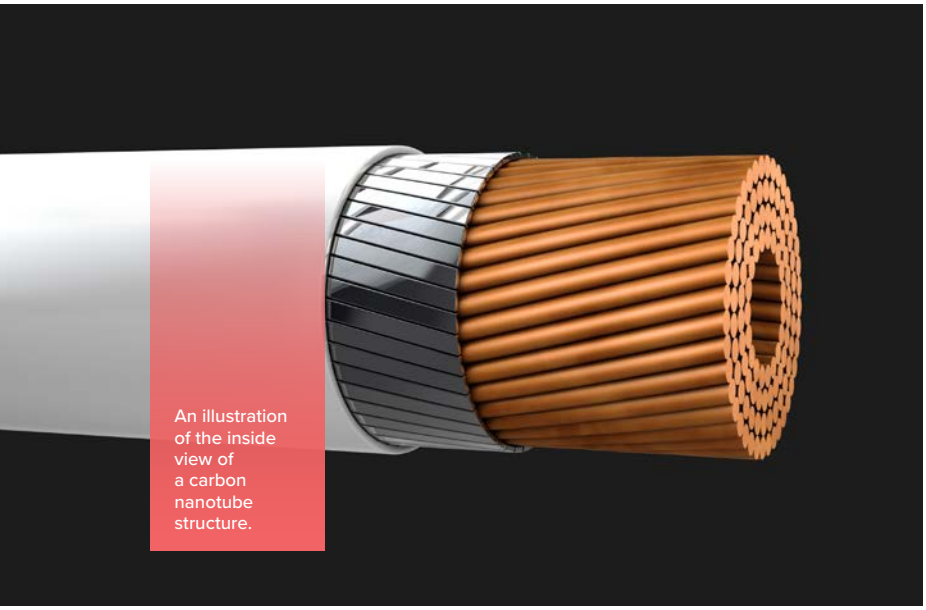
What inspires you?

I have always been captivated by the realm of nanotechnology. At the nanoscale, materials exhibit properties that are absent or limited at the macroscale and emerge at the nanoscale. For example, several nanomaterials exhibit significantly greater strength compared to their bulkier counterparts. The classical examples are graphite and graphene: graphite, a brittle material that allows you to write with a pencil, stands in contrast to graphene, which consists of a single layer of carbon atoms and is one of the strongest materials in the world.

How would you sum up your research interest and expertise?

My research journey began with exploring ways to enhance the strength of concrete and polymers by mixing them with innovative nanomaterials. I began working with carbon nanotubes during my tenure at Texas A&M University and then gradually turned to graphene. Currently, I specialize in digital design and 3D printing, a form of additive manufacturing where 3D objects are created by adding material layer by layer.

STOCKTREK / DIGITALVISION / GETTY IMAGES PLUS



An illustration of the inside view of a carbon nanotube structure.

TUSSIK13 / ISTOCK / GETTY IMAGES PLUS

I have also embarked on integrating graphene and other 2D materials, such as MXenes, into very complicated, lightweight 3D-printed objects. The term "MXene" is derived from their structure, where "M" represents a transition metal and "X" is carbon and/or nitrogen. These materials show interesting electronic and mechanical properties.

My research group achieved the first fabrication of very porous 3D-printed materials made of graphene and MXenes. Over the past eight years, we have become experts in producing 3D micro-architectured materials and characterizing their mechanical and physical properties.

Do you envision the applications of these materials, especially in the aeronautics sector?

There are several possible applications for these materials. For instance, these special materials with graphene and MXenes can be designed to dissipate heat generated by electronic devices, preventing overheating. Their large surface area and excellent electrical conductivity make them ideal also as catalytic substrates and electrodes for energy storage devices.

In the aerospace industry, composites enhanced with 2D materials can add strength and special properties, such as self-sensing and self-healing. Imagine 'smart materials' that trigger an alarm when they sense damage.

Additionally, 2D materials can revolutionize electromagnetic shielding and absorption in defense-sector aircraft. For example, their use could prevent interception or jamming of the aircraft's own emissions by adversaries.

Graphene and other 2D materials also excel in thermal conductivity and can act as efficient thermal barriers. They dissipate heat away from the ignition source, preventing the rapid spread of fire. Graphene can achieve these results with significantly lower concentrations compared to conventional fillers, such as carbon black.

What was the key take away from the symposium on 2D materials?

As well as presenting my group's results, I attended presentations from different industries that showcased a multitude of successful applications for 2D materials, along with the challenges faced. I gained valuable insights and was intrigued by companies that have achieved remarkable success with 2D materials. As a result, I'm initiating discussions with these companies to explore potential collaborations.

What advice would you give to aspiring PhD students with an interest in 2D materials?

The world of 2D materials is vast and continuously expanding. I would encourage aspiring PhD students to focus on a single application and identify the most promising 2D material for that application.

1. Ashraf, J., Fu, J., Liao, K., Chan, V., Abu Al-Rub, R.K. Scalable synthesis, characterization and testing of 3D architected gyroid graphene lattices from additively manufactured templates. *Journal of Micromechanics and Molecular Physics*, Vol. **6**, No. 3, pp. 13–24 (2021).

2. Fu, J., Taher, S.E., Abu Al-Rub, R.K., Zhang, T., Chan, V., Liao, K. Engineering 3D-architected Gyroid MXene scaffolds for ultrasensitive micromechanical sensing. *Advanced Engineering Materials*, Vol. 24, No. **7**, 2101388, pp. 1–13, 2022.

3. Ashraf, J., Taher, S., Lee, D.-W., Liao, K., Abu Al-Rub, R.K. On the computational modeling, additive manufacturing, and testing of tube-networks TPMS-based graphene lattices and characterizing their multifunctional properties, *APL Materials*, Vol. **10**, 121107, pp. 1–18, 2022.

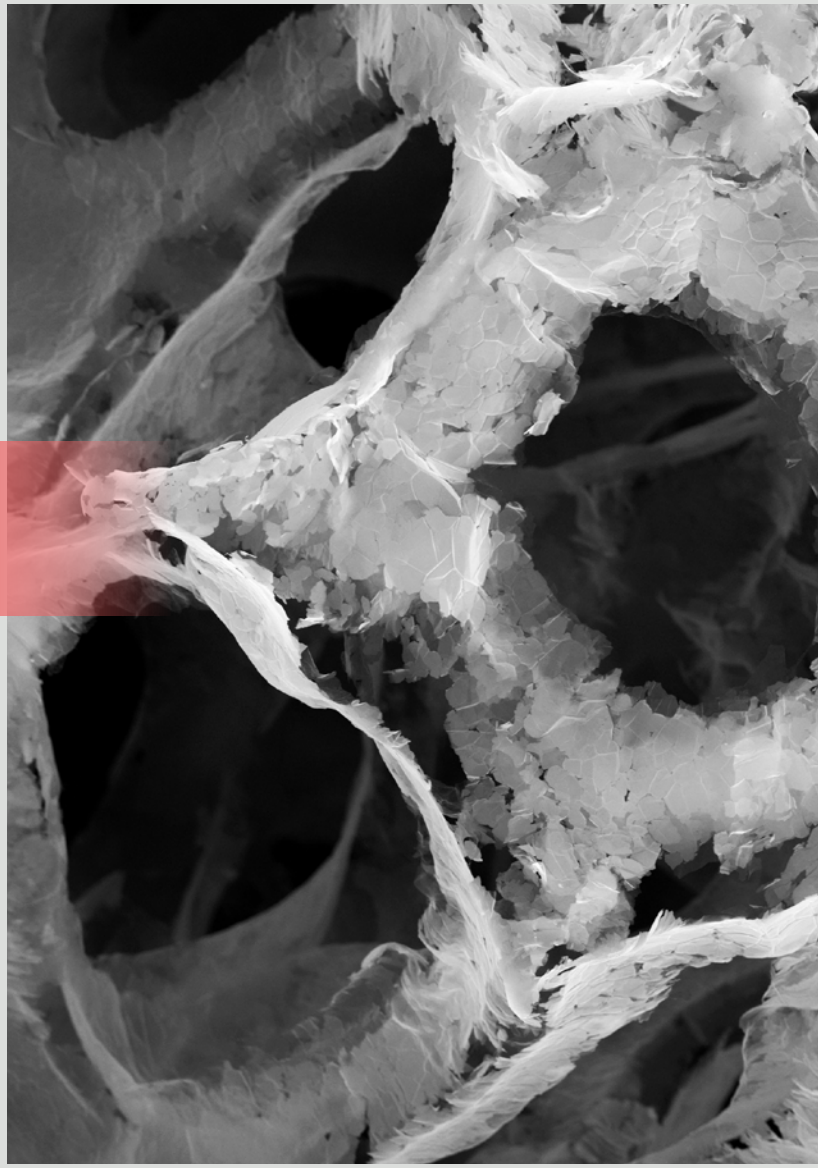
SCIENTIFIC DEFINITIONS AND FACTS

Graphene-based sensors

are sensors that are embedded within the fiber reinforcement of composite structures during manufacture and which can offer a convenient means to monitor quality control and structural health of vehicles such as aeroplanes, spacecraft and ships.

Endless possibilities in 2D

RIC2D symposium speaker Jang Kyo Kim's work showcases the remarkable potential of graphene and other crafted materials.

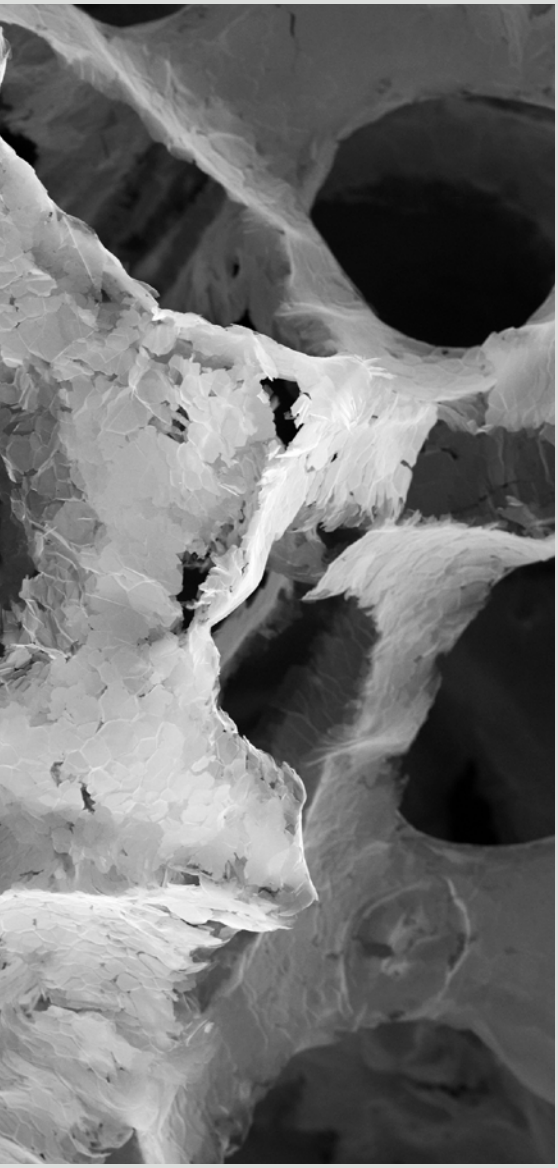


A scanning electron microscopy (SEM) image of graphene foam's network structure.

Fascinated by the science and endless possibilities of 2D materials, Professor Jang Kyo Kim, a professor of mechanical engineering, joined Khalifa University's faculty in January 2023.

Originally from the Hong Kong University of Science and Technology, Kim is well connected with researchers in China, Hong Kong, South Korea and other parts of Asia.

Currently, he is in the process of establishing collaborations across Europe to propel graphene research into the next phase of innovation.



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Tell us about your research goals.

I am interested in discovering how graphene can be assembled to form interesting structures or mixed with other materials to produce composites with multifunctional characteristics. For instance, materials that possess strength, high conductivity and effective heat dissipation simultaneously.

What type of structures can you create? And which techniques do you use?

We create 2D and 3D structures using various techniques. For example, starting with graphite, the same material as pencil lead, my team developed a method to obtain thin sheets of graphene oxide. We separated the larger sheets (50-300 µm in lateral size) and assembled them into thin 2D structures, including conductive graphene papers and transparent graphene films. We have also created 3D structures, such as graphene foams and aerogels. Aerogels are one of the lightest solid material types that currently exist.

What type of applications are there for such materials?

Graphene paper, for instance, possesses both strength and conductivity, making it suitable for use in supercapacitors—energy-storage devices that can be charged and discharged faster than batteries. Transparent graphene films low resistance, can be employed and could be applied to flexible touchscreens and electronics. The porous structure of graphene aerogels makes it useful for storing ions in energy storage devices, or to trap contaminants in environmental filters. These are just some examples of a possibly endless list.

What application of graphene excites you the most?

Composites formed by combining graphene aerogel and polymers currently represent some of the most promising applications. For example, my team worked on the complex challenge of developing a composite material with multifunctional capabilities, including excellent dielectric properties, energy density and thermal conductivity. In simpler terms, our aim is to create a material capable of efficiently storing energy within a compact volume while effectively dissipating heat. We achieved good results by adding boron nitride and graphene aerogels to a commercial polymer.

We also fabricated composites designed for electromagnetic interference (EMI) shielding. EMI occurs when waves carrying signals, such as radio waves or Wi-Fi, interfere with each other.

EMI-related issues are expected to grow. Graphene-based 2D and 3D structures can effectively reflect, attenuate and absorb EMI thanks to their excellent electrical properties.

1. Lin, Xiuyi, et al. Fabrication of highly-aligned, conductive, and strong graphene papers using ultralarge graphene oxide sheets. *ACS nano* 6.12 (2012): 10708–10719.
2. Zheng, Qingbin, et al. Transparent conductive films consisting of ultralarge graphene sheets produced by Langmuir–Blodgett assembly. *ACS nano* 5.7 (2011): 6039–6051.
3. Yousefi, Nariman, et al. Highly aligned graphene/polymer nanocomposites with excellent dielectric properties for high-performance electromagnetic interference shielding. *Advanced Materials* 26.31 (2014): 5480–5487.
4. Guo, Fengmei, et al. Highly thermally conductive dielectric nanocomposites with synergistic alignments of graphene and boron nitride nanosheets. *Advanced Functional Materials* 30.19 (2020): 1910826.
5. Wu, Ying, et al. Ultralight graphene foam/conductive polymer composites for exceptional electromagnetic interference shielding. *ACS Applied Materials & Interfaces* 9.10 (2017): 9059–9069.

Predicting surface stress response of crystals through code

Elastically bendable molecular crystals can be used in flexible semiconductor devices without significant loss in electron mobility.

Custom-developed computer code that accurately calculates the mechanical properties of molecular crystals is revolutionizing materials discovery and providing deeper scientific insights into the complex behavior of molecular crystals.

MechaPredict, a Python code developed by Sharmarke Mohamed's group in the Green Chemistry and Materials Modelling Laboratory at Khalifa University of Science and Technology, is at the heart of this groundbreaking work. The code relies on elastic constants generated using density functional theory, a quantum mechanical method for modelling solid-state materials.

"The code takes as input a crystallographic information file and the elastic constants for the crystal, as well as a user-specified set of Miller indices for crystal surfaces of interest. It then computes the facet-dependent mechanical properties of the crystal within seconds," explains Mohamed. "The estimates of the mechanical properties from MechaPredict are in excellent agreement with experimental nanoindentation measurements for crystals that comprise strong cohesive intermolecular forces, such as amino acids."

Unlike crystals derived from metals and ceramics, where the composition is less variable, molecular crystals are composed of covalently bonded chemical fragments that can be reconfigured in an endless number of ways via bond-breaking and bond-formation events. This brings numerous opportunities for customizing the crystal's behavior.

"Small changes in the chemical structure of these fragments can have significant effects on the properties of the crystal. This in turn offers more scope for discovering new molecular crystals for various technological applications," says Mohamed.

Globally, there is now intense activity around the investigation of molecular crystals, with researchers keen to identify new useful examples and better understand their behavior. In a recent Chemical Science paper[1] Mohamed and colleagues showed that elastically bendable molecular crystals can be used in flexible semiconduc-

KARL GAFF / SCIENCE PHOTO LIBRARY

tor devices without significant loss in electron mobility.

"Our code allows high-throughput screening of the mechanical properties of crystals without doing a number of serial and time-consuming nanoindentation experiments," Mohamed says. "The code also allows us to gain a deeper understanding of how molecular crystals deform under applied stress. By doing careful density functional theory simulations of the facet-dependent changes in the stress response of crystals, we are now in a better position to understand, for example, why some crystals crack under stress while others can withstand significant stresses before they fracture."

MechaPredict is compatible with both Windows and Linux operating systems. Its user-friendly graphical interface makes it accessible and valuable to both theoreticians and experimentalists. Looking to the future, Mohamed's team is exploring the idea of integrating MechaPredict within a machine-learning workflow to predict not just the mechanical properties of molecular crystals but also the possible experimental conditions for targeting their discovery in the laboratory.

1. Samanta, R., Das, S., Mondal, S., Alkhidir, T., Mohamed, S., Senanayak, S.P. & Reddy, C.M., Elastic organic semiconducting single crystals for durable all-flexible field-effect transistors: insights into the bending mechanism. *Chemical Sci*ence **14**, 6 (2023).

Graphene-based sensors are set to transform structural monitoring

Smart sensors will be game changers in aerospace and automotive and marine applications, where they could soon be embedded in structures to detect manufacturing defects.

Graphene-based sensors embedded within the fiber reinforcement of composite structures during manufacture could offer a convenient means to monitor quality control and structural health of aeroplanes, spacecraft and ships. These sensors have the potential to not only warn of manufacturing defects but also to identify hard-to-see damage from impacts and excessive stress during operation.

Rehan Umer and coworkers from the Department of Aerospace Engineering at Khalifa University describe the role that sensors made from reduced graphene oxide (rGO) could play in Industry 4.0, as the fourth industrial revolution is known, especially for aerospace, automotive and marine applications.

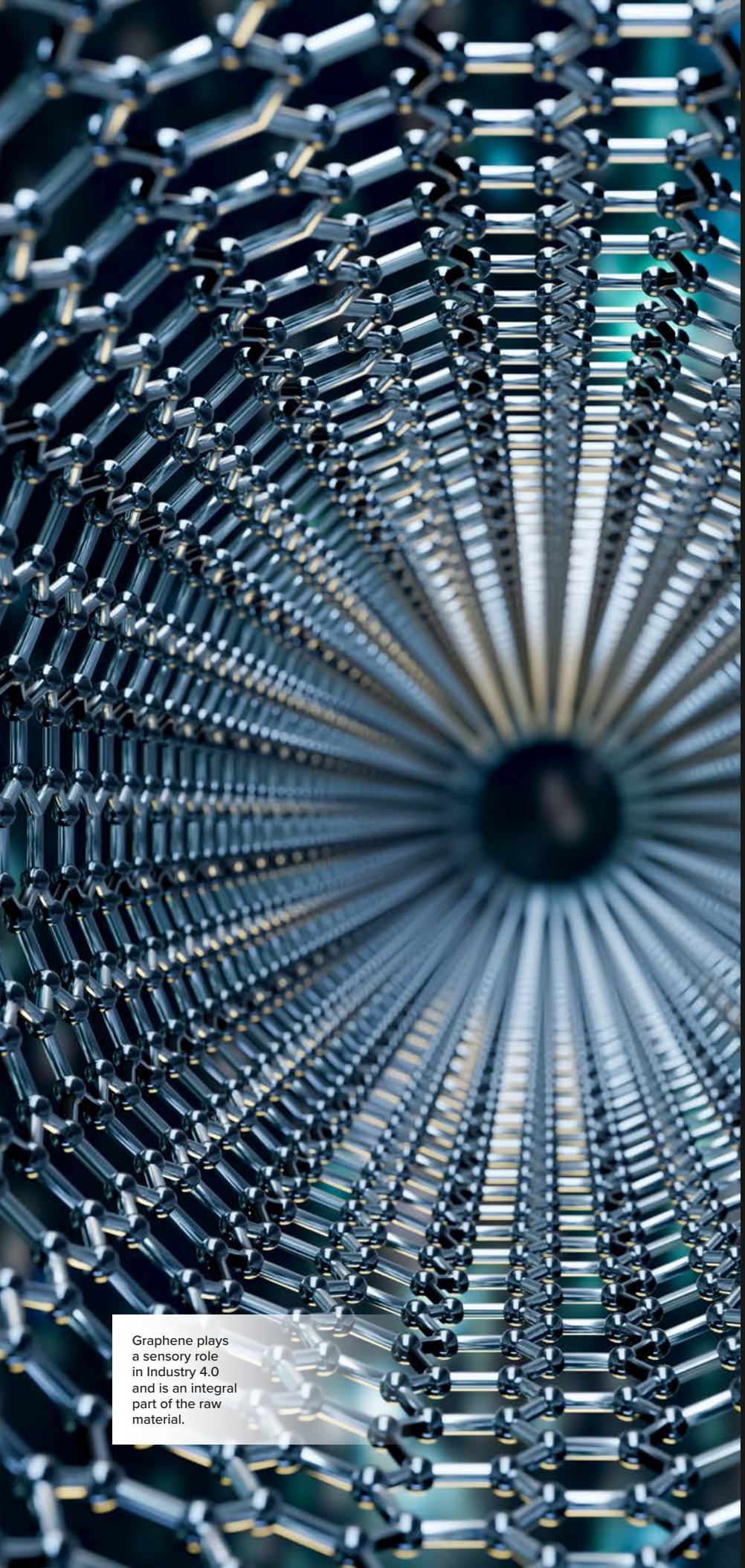
Industry 4.0 refers to the latest trend in manufacturing, where information technology—especially smart sensors, the internet of things, and artificial intelligence—introduces useful data and added value into production processes and operation.

"The main role of graphene in the Industry 4.0 factory is as a sensory element, while being an integral part of the raw material," explains Umer. "Graphene and other 2D materials can act as the required interface and allow the material to directly communicate with the digital world by producing an enormous amount of data during the product's manufacturing and its service life," he adds.

Reduced graphene oxide is well suited to the role due to its piezoresistive response, meaning that any change in stress or strain results in a change in electrical resistivity, which can easily be measured. It is also lightweight, mechanically robust, noninvasive and compatible with polymer composites, Umer says.

"These sensors can be embedded within a skin of an aircraft to sense its overall health, at the same time they can also monitor impact damage that is barely visible to the naked eye," explains Umer. "Given the piezoresistive nature of rGO, several polymer-composite manufacturing parameters can be monitored such as compaction forces, resin or polymer flow and shrinkage strain during manufacture."

"Sensors can be embedded in an aircraft's skin to sense its overall health and can monitor impact damage barely visible to the naked eye."



Graphene plays a sensory role in Industry 4.0 and is an integral part of the raw material.

SABINA ILIESCU / 500PX/ GETTY IMAGES

The research team is now investigating the best way to incorporate rGO into the composite. Options include integrating it into the resin matrix, weaving it into the structure or coating the final composite, says Umer who notes that an additional challenge is calibrating the sensor after it has been embedded.

The Khalifa team says that it has already demonstrated the use of post-manufacture structural monitoring devices such as pressure-sensitive films and strain-measuring gauges. Patents for in-mold pressure measuring sensors have been applied for in the United States, with further development ongoing. “A large-scale production system is essential for the commercialization of rGO as a viable digital material,” concludes Umer.

Did you know?

Industry 4.0 refers to the latest trend in manufacturing where information technology introduces useful data and added value into production processes and operation.

Ali M.A., Irfan, M.S., Khan, T., Khalid, M.Y. & Umer, R. Graphene nanoparticles as data generating digital materials in industry 4.0. *Scientific Reports* **13** 4945 (2023).

OVERCOMING CANCER'S RESISTANCE TO TREATMENT

Mohamed Rahmani, Professor, Department of Molecular Biology & Genetics at Khalifa University.

An international scientist, Mohamed Rahmani studied in France and worked for a long period in the United States at the Virginia Commonwealth University's Massey Cancer Centre. He joined Khalifa University in 2021 from the University of Sharjah. He is a professor in the Department of Molecular Biology and Genetics.

What are your current research goals?

It is estimated that 90% of chemotherapy failures are attributed to drug resistance. Cancer cells can develop resistance to one or more drugs through various mechanisms, including DNA mutations, loss of a drug's ability to inhibit its target, or the activation of survival pathways in cancer cells. My primary research goals are to identify vulnerabilities in tumor cells and contribute to the development of novel, effective strategies to overcome cancer's resistance to treatment.

How did you become interested in cancer research?

As a graduate student in the 1990s, I was fortunate to work with a team of researchers focusing primarily on cancer. I was captivated by the dysregulation of gene expression in cancer cells, and their capacity to sustain uncontrolled growth. This fascination was profoundly shaped by my personal experience witnessing a close family member battling cancer. It instilled in me a deep sense of commitment to advancing research and developing more effective treatments to improve the health of cancer patients.

What are your main findings so far?

We investigated a type of Acute Myeloid Leukemia caused by mutations in a protein known as FLT3, which plays a crucial role in the growth and development of blood cells. When this mutated protein is hyperactive, it triggers uncontrolled growth and proliferation of immature blood cells in the bone marrow, leading to the disease. We have uncovered a novel combination therapy that has shown a remarkable potential in curing leukemic mice and overcoming drug resistance to the therapies in use today.

Are there any biomedical technologies that hold particular promise for advancing your research?

One of the most important advances in biomedical research in the last decade has been the discovery of CRISPR-Cas9 gene editing technology. This versatile tool has many applications in biomedical research, for example, it allowed us to identify genes responsible for drug resistance through genome-wide screens with CRISPR-Cas9. Another cutting-edge technology is single-cell sequencing, which tells us about changes occurring within individual tumor cells. This technology holds immense promise for characterizing tumor heterogeneity, identifying potential targets, and informing therapeutic interventions.

What advice do you have for aspiring PhD students interested in pursuing a career in your field?

A PhD in biomedical sciences is an exciting journey filled with challenges and opportunities. It opens the door to a new world where you can actively engage with a scientific community dedicated to shaping our future healthcare. Success in this adventure hinges on collaboration with researchers within and outside your own field, diversification of skill sets, and persistence in the face of difficulties.

What do you find most rewarding about working at Khalifa University?

I joined Khalifa University a little over two years ago and find immense satisfaction in working for a university that is having such a global impact in various fields including health sciences. I am particularly impressed by our institution's unwavering commitment to excellence in research, teaching and service, as well as the resources it allocates. This establishes a strong platform that allows me to address complex scientific questions, while encouraging continuous improvement and the pursuit of high academic standards.

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