ON THE FRONTLINE OF THE BIOMEDICAL REVOLUTION

The 21st century has seen a boom in biomedical advances, aided by increased recognition of the importance of working across different scientific disciplines. Materials and methods for the detection and treatment of diseases are better than ever, and a diverse array of scientists at the **University of Technology Sydney (UTS),** Australia, led by **Professor Dayong Jin**, are at the forefront of this continuous development.

Professor Dayong Jin FTSE

Director, Institute for Biomedical Materials & Devices (IBMD); Science Director, ARC Research Hub for Integrated Device for End-user Analysis at Low-levels (IDEAL); Co-Director, DISER Australia-China Joint Research Centre for Point of Care Testing, Technology Director, ARC Centre of Excellence for Quantum Biotechnology, University of Technology Sydney (UTS), Australia

Field of research
Biomedical Materials and Devices

Research project
Using photonics to investigate the behaviour of cells and molecules, to inform biomedical applications

Funders
Australian Research Council (ARC), Australian Department of Industry, Science and Resources, National Natural Science Foundation of China, Shenzhen Science and Technology Innovation Commission

PROFILE

TALK LIKE A ...

BIOMEDICAL SCIENTIST

Antigen — a substance, usually produced by a pathogen, that induces an immune response in the body

Biomedicine — the application of biological principles to medicine

Diagnostics — techniques used for identifying (for example) a disease

Imaging — making a visual representation of something through scanning it with a detector or electromagnetic beam

Materials science — the study of the properties of materials and how they relate to composition and structure

Organelle — the specialised structures within a cell

Photonics — the branch of science dealing with photons (light particles)

Have you ever taken a PCR or lateral flow test? Have you heard of PPE (personal protective equipment)? It is likely you can answer yes to both questions because biomedical science is booming – and for good reason. Our understanding of the world has changed irrevocably since the COVID-19 pandemic, and elements of biomedicine which we would not have considered before are now very familiar to us. Although the pandemic upended our lives, a silver lining of its devastating impact has been the worldwide recognition of the critical importance of biomedicine, leading to a tidal wave of resources, funding and expertise being channelled into the sector. "Now, you can see the field is thriving after the pandemic," says Professor Dayong Jin, Director of the Institute for Biomedical Materials & Devices (IBMD) at the University of Technology Sydney (UTS). "Diagnostics, imaging, materials science – people now realise how important it is."

Biomedicine in the limelight

Every response to the pandemic depended on biomedical materials and devices, ranging from straightforward prevention measures such as masks, through to the development of rapid detection methods, PCR (polymerase chain reaction) technology and vaccines. "These responses have only been possible in recent years," says Jin. "If COVID-19 had arisen twenty years ago, before ultrasensitive detection techniques, PCR technology and RNA vaccines were widely available, it would have been a much greater nightmare."

Despite successes in combatting the disease, though with heavy societal losses, Jin says that the COVID-19 pandemic highlighted the critical need for further biomedical advances. "Another pandemic will come in the future, and we need to focus on developing the technology and expertise to address it," he says. "Antibiotic-resistant bacteria are on the rise and could spark the next pandemic." Recognising this threat, Jin's team is starting to work on examining methods for detecting such bacteria. "You always have to look several steps ahead," he says. "If you only have the tools to address immediate problems, you're not prepared for problems of the future."

Into the light

Jin specialises in using photonics – the science of light – within biomedicine. "We developed the rapid antigen test for COVID-19, using

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optical devices to detect viral proteins," he says. Jin's photonics research uses nanotechnology to see how light interacts with molecules themselves, which relies on drawing expertise from different areas. "We have photonics and nanoscale photonics, and we are even starting to have quantum photonics," he says. "These technologies were developed by scientists and then translated by engineers to be used within biomedicine."

A lot of this area of study depends on understanding the material properties of different substances and molecules. "We are constantly discovering new material properties that show fascinating light behaviour," Jin explains. "You can manipulate light for different applications. Handheld devices for detecting tell-tale molecules that indicate disease are increasingly becoming a reality." Jin's team is working on ever-more sensitive technologies for viral detection, alongside examining how viruses mutate and interact with host cells.

> "WE ARE CONSTANTLY DISCOVERING NEW MATERIAL PROPERTIES THAT SHOW FASCINATING LIGHT BEHAVIOUR."

Looking forward

Jin's team is currently investigating the fine but critical details of cellular science. "My team is trying to understand how cells function, how they metabolise, and how the organelles within cells work together and communicate with one another," he says. "In particular, we're developing new tools and technologies to examine these fundamentals of life, which has big implications for our understanding of how cells work."

On the broader scale, while there have been countless scientific breakthroughs in recent years, not all have yet made it into the real world. "There's a lot of exciting science out there, but for it to be useful for society, it needs to be translated into accessible technology that can be commercialised," says Jin. "The other potential limitation is people. We need to continuously train people to understand and use this new technology, as well as make further advances." For this reason, Jin sees high and ever-growing demand for biomedical scientists and engineers in the future, with exciting opportunities for new entrants into the field.

Jin's life as a *biomedical scientist*

"Growing up, I always asked lots of questions. I loved building things, such as with LEGO, and enjoyed mathematics – I was always quite good at it.

"I started my career as an experimental scientist. I was sure I would do something related to science and technology, but wasn't sure whether it would be in industry, government or academia. Fortunately, I didn't need to make that decision at that stage. I enjoyed playing with optics and lasers in the lab, which paved the way for my career progression. And I still enjoy playing with optics today – it's not so dissimilar to LEGO!

"Recognition is rewarding, and I'm always proud to say I'm a professor. My family is proud of me, and being a professor is also a well-paid job. Many professors are also entrepreneurs who start companies to get technologies into the market. Though we work long and sometimes unsociable hours, we have a good degree of flexibility.

"I think I've achieved a lot. I've won many awards and prizes, but when I look back, it's the people that really matter – the students I've trained and supervised, the colleagues I've collaborated with, the friendships I've made. They are my biggest source of pride.

"I always say to my kids that the most important skills are reading and writing, closely followed by maths. No matter what scientific profession you follow, you'll never avoid maths, and good communication skills are also a must.

"I confess, I'm a typical workaholic! But I feel this is okay as long as you like it. People say that you need persistence to overcome challenges, but I have a different strategy – if you find an obstacle, don't let it slow you down. Instead, find a challenge you feel competent to do. You can go back to the original obstacle when you feel ready. There is always plenty to do as a scientist, so if one task isn't working, you can set it aside for a while and work on other priorities."

GLOSSARY

Cardiovascular — relating to the heart and blood vessels

Nanoparticle — a tiny particle at the nanometre scale

Optical — relating to light

Probe — a molecule (used in research) that binds to a specific substance in a sample and can then be detected by a sensor

Dr Jiajia Zhou

PROFILE

Associate Professor, School of Mathematical and Physical Sciences, Faculty of Science, UTS

Fields of research
Materials Science and Engineering, Spectral Physics

Research project
Developing novel probes, sensors and diagnostic technologies for a range of societal and industry applications

Funders
Australian Research Council (ARC), The National Health and Medical Research Council (NHMRC)

Meet Jiajia

"My curiosity inspired me to become a scientist. I always wanted to know why and how things worked. My quiet personality is also well suited to a career in academia.

"I find it very rewarding to translate my research into useful probes and sensors. Going on to make devices that meet specific needs shows the real-world value of my work.

"Nanoparticles remain mysterious. There are plenty of questions still to be answered, such as how nanoparticles and antibodies interact. On the practical level, we also need to find ways to scale up nanoparticles to behave consistently, so we can roll them out to meet industry needs.

"I enjoy a great research environment in a rapidly advancing field. Working hard and working intelligently has helped me find success here."

Jiajia's *research*

The work of the Institute for Biomedical Materials and Devices (IBMD) demands the development of clever tools that can sense molecules at the nanoscale. This is where materials scientists and engineers, who have the expertise to do exactly that, come in. Dr Jiajia Zhou, Associate Professor at UTS's School of Mathematical and Physical Sciences, is leading the research and development of a range of innovative detection methods.

Probes and their uses

The development of optical probes, such as those used by Jin, is a core area of research for Jiajia. Probes are microscopic substances that are added to a sample and then change state in some way when attached to a specific molecule. They can then be detected by a specific sensor. Optical probes, for instance, change their optical properties when attached to their molecule of interest, meaning they interact with light in a different way. "My work on probe and sensor development is complementary to Jin's photonics and microscopy expertise," says Jiajia. "The unique probes and sensors we make are key elements for making biomedical devices."

Applications for such probes are diverse. "As well as testing for COVID-19 antigens, another practical application of these probes is quantifying proteins in dairy milk," explains Jiajia. "By measuring A1 and A2 proteins, we can provide dairy farmers with improved quality assurance processes." Milk with a lower proportion of A1 proteins may be more digestible for people intolerant to conventional milk products.

Nanoparticles

The rise of nanoscience is vastly increasing the potential for probes. Probes constructed from nanoparticles can enter cells themselves, attaching to proteins or other substances within the cell. Jiajia has discovered a new process to develop nanoparticles that convert light from infrared to visible at a high level of efficiency, which now have strong potential to be used as probes.

Now, Jiajia is leading her team to develop smaller, brighter nanoparticles that function as temperature sensors in living cells. "Temperature changes can be an indicator of organelle dysfunction, which can be an early sign of disease," she says. "Monitoring these changes could lead to important discoveries in early diagnosis and treatments for a diverse range of diseases – from cancer to cardiovascular diseases."

From theory to application

Like many researchers, Jiajia has seen her focus shift from theory to application in recent years. "Advances in physical sciences are being applied more and more to solve the needs of medicine and industry," she says. "Before the COVID-19 pandemic, my research was all about fundamental science, with the aim of publishing interesting findings in high-impact journals. Now, I've moved more to research translation – in other words, using my knowledge to address real-world issues like COVID-19."

Jiajia is becoming increasingly immersed in the practical applications of her research. "Over the next five years, I will specialise in ways to image and detect single molecules at high resolution," she says. "This will have applications for visualising interactions between viruses and host cells." Through advancing both the knowledge behind these behaviours, as well as developing methods and materials for detecting them, Jiajia's work will boost preparations ahead of the next pandemic.

GLOSSARY

Biomarker — a naturally occurring molecule that acts as a sign of a particular process (for example, a disease)

Clinical pharmacology — the study of the relationships between drugs and the human body

Point-of-care testing — a test with an analysis performed during or near to healthcare for the patient

Pre-eclampsia — a high blood pressure disorder that can occur during pregnancy

Dr Lana McClements

Associate Professor, School of Life Sciences, UTS

Field of research
Biotechnology

Research project
Developing biomarkers to detect early signs of pre-eclampsia and related conditions

Funders
Heart Foundation, NSW Cardiovascular Network, Maridulu Budyari Gumal: The Sydney Partnership for Health, Education, Research and Enterprise (SPHERE), Cardiac and Vascular Health Clinical Academic Group

PROFILE

Meet Lana

"My parents always encouraged my academic career. My father inspired me to be creative and innovative. I have also had some amazing supervisors and mentors throughout my career who have given me invaluable guidance and support.

"Biotechnology is a dynamic and constantly advancing field. New knowledge is being generated on a daily basis, with huge potential for improving people's lives and meeting industry needs. I find this scale of impact fascinating and inspiring.

"There are many opportunities in biotechnology, both in Australia and globally. The medical field always needs improved diagnostics, disease management and ways to boost people's quality of life. Digital health technologies are almost ready for home use, which will empower society with the knowledge and tools to take better care of their personal health.

"Hard work, passion, determination and resilience have been the keys to success in my field."

Lana's *research*

Dr Lana McClements is a trained clinical pharmacist who now manages a number of lab projects to develop new diagnoses and treatment methods. A core area of her research is finding ways to detect molecular indicators within blood – biomarkers – that reveal early signs of diseases such as pre-eclampsia, a complication of pregnancy. "Based on our discoveries in the lab, we're developing new tests to predict pre-eclampsia, both in the lab and at the point of care," she says. "These can then help develop the next generation of personalised treatments."

Pre-eclampsia

There is an increasing body of research indicating that many diseases begin to develop far before any physical signs are present, but, when digging down to the molecular and cellular level, the signs are there. Pre-eclampsia is the leading cause of death and complications when someone is pregnant, so addressing it before it develops would bring dramatic benefits. "Timely diagnosis and close monitoring can reduce risks of developing pre-eclampsia complications, including pre-term birth, and our biomarkers can identify pregnant women at risk of developing this condition even when they have no symptoms," says Lana.

Lana's work also goes beyond the pregnancy period and looks for solutions to safeguard long-term health. "For women who have had pre-eclampsia and their children, there is an increased risk of developing cardiovascular disease in the future," she says. Lana has worked with clinicians and biomedical engineers to screen for new biomarkers that detect early signs of cardiovascular disease in women who have had pre-eclampsia in the past, thus enabling the vulnerability to be addressed rapidly.

Knowledge base

Lana's research focuses on developing a biological understanding of disease. "Having a fundamental understanding of the underlying biology is critical when translating discoveries from the lab to the clinic," she explains. "We focus on building this knowledge base and developing advanced models of diseases in the lab, so our findings can be adapted and applied in a range of ways." This resource of knowledge is used by researchers of other specialisms, such as Jin, to develop practical applications based on these newfound mechanisms.

"We have been working with Prof Jin's group to translate our biomarkers into a point-of-care test to enable clinicians to make immediate and life-saving decisions for their patients," says Lana. "This test is highly sensitive, requiring only a small blood sample from the patient." This is an advantage for the research process, given that Lana's team can work with clinicians to gather samples from many patients to test the reliability and accuracy of their biomarkers, and also has big benefits for rollout in the real world too. "A key focus is making these tests as accessible as possible," says Lana. "Most pre-eclampsia deaths happen in remote areas or developing countries, so having point-of-care tests that are cheap and easy to use is critical for saving lives."

Like many diseases, pre-eclampsia can present itself in a multitude of ways, depending on the patient in question. "Our goal now is to understand the differences in the causes and manifestations of pre-eclampsia," says Lana. "This will help us develop personalised biomarker-based screening tests and treatments for patients, depending on the characteristics of the patient and disease."

GLOSSARY

Brillouin scattering — the process of light scattering on acoustic vibrations (pressure waves) within the material. Brillouin scattering is used to characterise mechanical properties of materials at the microscale

Brillouin microscopy — a microscopy technique where the sample is illuminated by a focused beam of light and the resultant Brillouin scattered light is analysed

Mechanical properties — physical properties such as elasticity and dissipation of mechanical energy

Optical physics — the study of the fundamental properties of light and its interaction with matter

Dr Irina Kabakova

Associate Professor in Optical Physics; Associate Head of School (Education & Students), School of Mathematical and Physical Sciences, UTS

Field of research
Optical Physics

Research project
Using Brillouin microscopy to examine micromechanical properties of cells and their responses to environmental changes and disease

Funder
Australian Research Council (ARC)

PROFILE

Meet Irina

"Being a scientist means that you always have a curious mind. Routine jobs might not satisfy your need to answer questions and learn more. This thirst for knowledge is rewarded within science – there's a lot of satisfaction to be had in a career in research, because you are able to propose and answer your own questions.

"I feel the 21st century is all about breakthroughs in biomedicine and biology. While the 20th century had many breakthroughs in physics, revolutionising our daily lives through the introduction of so many technologies (transistors, lasers and optical fibres), I believe the current century will see major advances in health and fundamental understanding of a cell. We will see advances in human lifespan, treatment of previously untreatable diseases, and new technologies that become fundamental to our future.

"All the biggest societal issues will require biomedical advances. Global pandemics, antibacterial resistance, climate change and energy crises all have serious implications for human health, with specific challenges that only biophysics and biomedicine provide the answers to."

Irina's *research*

Irina specialises in optical physics, in particular Brillouin microscopy, which uses a focused beam of light to examine micromechanical properties in biological samples. "In my lab, we look at the mechanical properties of biological materials and cells at tiny scales," she says. "Using light beams to do so means we don't damage the materials but can still examine how properties change when cells are showing signs of disease."

Exercise for cells

Cells are highly sensitive to their environment. This is especially true before they have become specialised, when they are still stem cells, such as within embryos or bone interiors. "Stem cells can differentiate in different ways, maybe becoming fat cells or muscle cells, depending on the environment they're in," says Irina.

Irina is specifically interested in how cells' mechanical properties – their local elasticity and viscosity – vary depending on their environment. "Just like us, cells need to exercise," she explains. "And, just like us, the type of exercise they do depends on what they are aiming for." While people might work out to change their mechanical properties – Pilates to increase their flexibility, weightlifting to improve strength, and so on – so cells adapt their mechanical properties to fulfil their ultimate function.

However, such changes are not always beneficial; cells also change when they are diseased. "When cells become cancerous, for instance, their behaviour and mechanical properties change," says Irina. "Their elasticity changes, and the cells become more flexible, helping them to detach from the tumour and spread throughout the body."

> **"WHEN CELLS BECOME CANCEROUS, FOR INSTANCE, THEIR BEHAVIOUR AND MECHANICAL PROPERTIES CHANGE."**

Fusion of disciplines

"For a long time, there were no tools to study how mechanical properties of the cells change as they react to their environment," says Irina. While the techniques that she uses were largely developed by physicists decades ago, they have only relatively recently been applied for biological purposes. "For about fifty years, the Brillouin scattering techniques we now use were only applied to physics and geology," she says.

This all changed with the rise of interdisciplinary science. "About twenty years ago, optical scientists in biology realised that the mechanical properties of cells are actually very dynamic and important, and these optical techniques could help us study them." Since then, physicists, biologists and optical scientists have collaborated in greater depth, leading to the rise of important discoveries.

GLOSSARY

DNA — the self-replicating molecule in almost all living molecules, that carries genetic information

Epigenetics — the study of changes in organisms caused by changes in gene expression, rather than alteration of DNA itself

RNA — a 'messenger' molecule that carries instructions from DNA to inform the creation of proteins

Transcription — the process by which a cell makes an RNA copy of a gene

Translation — the process by which a cell reads an RNA molecule to create a protein.

Dr Yuen Yee Cheng

Associate Professor of Molecular and Cellular Biology, UTS

Field of research
Molecular and Cellular Biology

Research project
Studying how cells' epigenetic properties change in various cancers

Meet Yuen Yee

"As a kid, I always asked lots of questions and wanted to know the answers. I asked questions that not everybody did!

"Challenge energises me and keeps me working. My research has been very challenging, but once I've worked for a long time on one topic, I want to move on to the next challenge. Thinking about the application of research is always important. As scientists, there are always problems we want to solve, but a big part of good science is making sure the answers can be applied to real life. Yes, the science is amazing, but who is going to benefit?

"I enjoy the freedom I have at my current lab. Recently, I found an immunotherapy combination that could completely reject tumour growth in animals, and I also found a plant product that appears to suppress tumour growth. The practical applications of these findings are very exciting.

"Research still involves a lot of routine. For example, growing cells in the lab is repetitive, but the results can be amazing. While the process can be monotonous, it can be the trigger for something great."

Yuen Yee's *research*

Dr Yuen Yee Cheng is a molecular and cellular biologist, investigating how epigenetic alterations affect cancer development and progression. Epigenetics describes variations on top of our DNA that are interpreted by our body, which can change depending on the environmental conditions. While epigenetics underpins our development – it lets our cells adapt to different environments –, it also provides the answers for the cellular changes our body undergoes when diseased.

An epigenetics overview

"Epigenetics starts from very beginning of our development," says Yuen Yee. "For instance, in the womb, epigenetics controls how our hands separate into five fingers. During development, epigenetics leads to the death of cells between our fingers, so we develop five separate fingers. All our cells have the same DNA – different epigenetic profiles lead to different cell types," Yuen Yee explains. Her work investigates these epigenetic changes and how alterations in gene expression affect a cell's mechanical properties.

However, our cells' epigenetic properties can also be affected by agents that do not have the body's best interests in mind. While genetic diseases happen when there are errors in the DNA itself, most diseases emerge in different ways, such as through pathogens or particular environments. "While the DNA remains the same, our body's mechanisms for interpreting DNA change, causing changes to which proteins are expressed," says Yuen Yee. "It gets very complicated, very fast."

Cancers, Yuen Yee's principal area of interest, arise when something goes drastically wrong within a cell's genetic expression process, causing it to mutate and multiply in an uncontrolled manner. "I'm hoping that, soon, we will develop a lot of epigenetic biomarkers that are useful to identify early disease onset," she says. "Biomarkers help identify disease and also give an indication of how to develop treatment options."

> **"EPIGENETICS STARTS FROM THE MOMENT OUR CELLS BEGIN TO DIVIDE."**

Symbiosis

Currently, Yuen Yee is focusing on two types of RNA (circular RNA and microRNA), which are non-coding RNAs that move more freely through the cell and, ultimately, affect the translation of proteins. Her work depends on using methods developed by others. "I use the tools developed by other researchers such as Jin," she says. "His photonic instruments can be adapted to detect the properties of RNA." In return, Yuen Yee provides Jin's team with specialist biological knowledge to help it improve its tools for specific purposes. Sharing of knowledge and expertise is vital for all researchers.

Next, Yuen Yee wants to further use the nanoparticles that Jin and colleagues are developing. "The small scale of nanoparticles means you can get into the cell easier and introduce epigenetic biomarkers within cells themselves," she says. "These could light up RNA interactions, for instance – something that's never been done before. It's very exciting!

> **YOU ALWAYS HAVE TO LOOK SEVERAL STEPS AHEAD. IF YOU ONLY HAVE THE TOOLS TO ADDRESS IMMEDIATE PROBLEMS, YOU'RE NOT PREPARED FOR PROBLEMS OF THE FUTURE.**
>
> **JIN**

The team's *top tips*

YUEN YEE:

- Writing and communication skills are important. How you tell people about your amazing discovery is vital to ensure its real-world value and help secure funding.
- Practise your maths. It's training your brain!

LANA:

- As with any career, there will be ups and downs, but, as long as you love what you do, you will stay determined and resilient.
- Flexibility and adaptability are critically important.
- If you feel passionate about biotechnology, take opportunities to broaden your skills and your network. Engage in extracurricular activities, seek internships, and follow people and companies on LinkedIn.

IRINA:

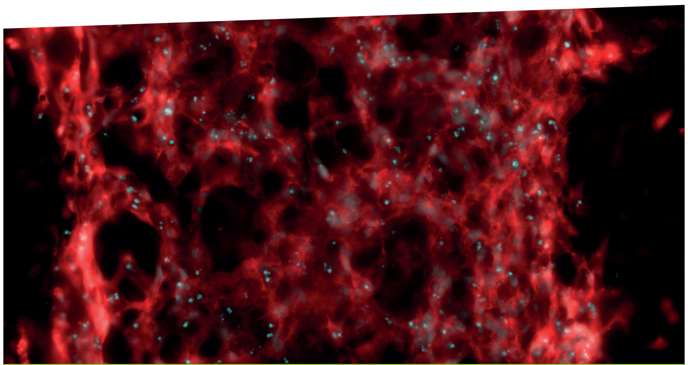
- A curious mind is essential to science. If you find yourself always wanting to find answers, you already have the scientific mindset.

JIAJIA:

- Follow your interests, and always work hard and work smart.

JIN:

- Curiosity is key. You need to ask "why?", and then be curious about why you asked it!



Vasculature forming within the placenta-on-a-chip model (© Ms Sahar Ghorbanpour)

Lana in lab

Explore careers in *biomedical science*

- The University of Technology Sydney has a variety of outreach programmes for high-school students, such as hands-on workshops, campus visits, work experience and public lectures. It also hosts a wealth of online outreach resources: **www.uts.edu.au/about/faculty-science/outreach/outreach-and-community**
- Optica is the leading society for optics and photonics research. It has a number of resources for high school students, schools and families to learn more about the field: **www.optica.org/en-us/get_involved/education_outreach**
- Careers in biomedicine vary widely and can involve working in academia, industry or government. According to SalaryExpert (**www.salaryexpert.com/salary/job/biomedical-scientist/australia**), the average base salary for a a junior biomedical scientist (with a PhD degree) in Australia is $110,739 (AUD) per year.

> **"AS SCIENTISTS, THERE ARE ALWAYS PROBLEMS WE WANT TO SOLVE, BUT A BIG PART OF GOOD SCIENCE IS MAKING SURE THE ANSWERS CAN BE APPLIED TO REAL LIFE. YES, THE SCIENCE IS AMAZING, BUT WHO IS GOING TO BENEFIT?**
> **YUEN YEE"**

Pathway from school to *biomedical science*

Jin and his colleagues emphasise the importance of a strong foundation in mathematics for most scientific careers. In addition, they note the importance of being able to communicate effectively, showing the value of subjects like English. Depending on interests and possible future specialisms, combinations of the three sciences will often be an expectation for universities.