



Advances in  
MedTech are  
revolutionising  
healthcare



THE UNIVERSITY OF  
MELBOURNE



# Shifting focus from treatment to preventative healthcare

People's quality of life could improve significantly and even be prolonged if clinicians could predict disease onset and medical events such as a fall, heart attack or seizure. We could treat diseases more effectively – and even cure them.

With advances in computational medicine – using computer models and advanced software to simulate disease progression – this vision could be less than 10 years away from becoming reality. Combined with real-time data and artificial intelligence (AI), patient diagnosis, treatment and preventative care are poised for transformative change over the next decade.

Research is shifting healthcare's focus from one-size-fits-all solutions to personalised medicine tailored to individuals. From digital twins of individual organs to whole-of-body models updated with real-time data from sensors and wearables, researchers at the University of Melbourne are building medical technologies that recognise the complexity of each human body and the physical, cognitive and environmental factors that affect it.

Advances in personalised devices and new materials development are improving patient care. Research is propelling development in bionic ears and eyes, and in brain-powered devices that can give people who have lost mobility a greater degree of independence. Researchers are also creating biological materials that can regenerate previously irreversible damage or be used as scaffolding in the body and then dissolve.

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This is one small aspect of the medical technology research taking place at the University of Melbourne that offers unique opportunities to enhance the lives of millions of people globally. Research teams are collaborating with companies in drug discovery and simulation technology, working towards a 10-year vision where real-time digital analysis informs clinical decision-making for optimal drug combinations and recovery strategies. They are engaging with communities and patients to ensure their work is transparent, inclusive and rigorously aligned with societal needs and values.

# Harnessing the potential of digital twin organs

Moving to predictive, real-time health monitoring systems from traditional, reactive diagnoses is one of the most significant trends emerging in digital health research. It's creating more efficient and effective ways to enhance the lives of patients who have cancer, cardiovascular disease, diabetes, liver and kidney dysfunction and other chronic conditions.

Researchers are harnessing 'digital twin' technology to do this. They are creating virtual models of human organs, such as the heart or liver, updated with real-time, personalised data. Combining simulation and machine learning helps capture the dynamic nature of human physiology. This is advancing our understanding of fundamental biological processes such as cellular metabolism, calcium regulation and organ adaptation mechanisms.

Associate Professor Vijay Rajagopal and his team at the University of Melbourne are developing mathematical models to predict what will happen to a heart in real-time. Their aim is to get these models to seamlessly integrate a constant stream of collected data – such as heart rhythm, blood pressure and oxygen saturation – with medical imaging, genetic information and metabolic markers. Using AI, researchers are unlocking insights into how the heart adapts to stress, ageing and disease conditions.

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Digital twin technology is already moving beyond theoretical models into practical clinical applications. Associate Professor Rajagopal's team is collaborating with Austin Health, using CT scans to investigate aortic dissection, a condition in which a tear in the aorta creates false lumens or channels of blood flow that can lead to severe complications and death. The aim of the research is to use AI to analyse the data to enhance digital twin modelling capabilities and detect the risk earlier than current methods allow.

This technology will enable truly personalised medicine by creating individual-specific models that account for genetic variations, lifestyle factors and unique physiological responses. It represents a move away from population-based treatment protocols towards precision interventions tailored to cohorts of patients with a particular disease.

The implications extend beyond treatment selection to drug discovery and development, where digital models can accelerate the identification of therapeutic targets and reduce the time and costs associated with bringing new treatments to market.

Over the next decade, the collaborative nature of this technological development, built on open-source platforms and shared research efforts across international institutions, suggests these innovations will become increasingly accessible.

Digital twin technology can extend sophisticated digital health capabilities beyond major metropolitan hospitals to regional and remote healthcare centres. This democratisation requires robust digital infrastructure and user-friendly interfaces so that healthcare providers with varying technical expertise can use advanced computational tools.

# Personalising patient care in biomechanics

Every individual has unique body measurements, different levels of activity, varying bone density and a distinct genetic makeup. Using the 24/7 monitoring data available from wearables and smart implants provides exciting opportunities for researchers in the field of biomechanics to turn personalised medicine into a reality for everyone.

Biomechanical engineers often treat the body like a machine, with muscles as cables and bones as levers, to assist them in designing implants, prosthetics and assistive devices. However, this approach neglects numerous factors, including cognitive and environmental factors that can seriously affect mobility and doesn't always provide the best possible outcome for the patient. This has led researchers to change their focus to recognise the complex interplay of factors that influence human health and performance.

This human-centred approach is the core focus for researchers at the University of Melbourne's biomechanics research group, led by Professor Peter Vee Sin Lee. The researchers acknowledge that preventing falls in older adults, for example, is not just about measuring muscle strength. It involves understanding the intricate relationships between muscle control, vision, hearing, cognition, medications and even psychological factors such as a person's fear of falling.

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Professor Lee's research group designs personalised medical devices using the 4M (measure-model-manufacture-manage) approach. Researchers at the University of Melbourne are using this methodology to create patient-specific implants. They first measure individual anatomy and biomechanics, then model personalised devices virtually before manufacturing them using 3D-printing technology.



Professor Lee has used the same 4M approach to produce prosthetic limbs for lower limb amputees in developing nations. Every year an estimated one million people across the globe have a limb amputated, so the potential impact of this research is significant. Seeing the need for an accessible and low-cost solution, Professor Lee's team created a method of fabricating a prosthetics socket using the pressurised-casting (PCAST) method, which uses water pressure to shape the socket according to the patient's limb. Professor Lee is currently working with the Global Peace Network, a Canadian non-government organisation, to upskill health workers in Tanzania and South Sudan to use the PCAST system.

Measuring biomechanic signals can provide early warning of health threats. University of Melbourne researchers are developing an early warning system for the human body to detect health threats using cognitive, human movement and speech data. They are using Australia's only Computer Assisted Rehabilitation Environment (CAREN) developed by Motekforce Link to collect multimodal behavioural biometrics. Upon exposure to a pathogen, protective measures are activated by a person's innate immune response. Before symptoms like a fever begin, there can be subtle changes in a person's cognition and gait, for example. University of Melbourne researchers aim to use such behavioural changes to detect acute infection rapidly.

The research team's long-term goal is to create a personalised human digital twin that can track and simulate a person's health and behaviour in real time. The digital twin will be built with information from multiple sources, including wearable devices, which monitor things like physical activity, brain activity and daily habits. By combining this personal health data with information about someone's environment, the digital twin could give clear, useful advice to help people improve their health, optimise personal performance and make better decisions about their wellbeing. And the digital twin could keep learning, adapting and evolving based on a person's real-life experiences.

This vision extends to preventative healthcare where clinicians could virtually test their patients' responses to different scenarios – from slip-and-fall situations to marathon training – using their digital twin to optimise health outcomes and prevent injuries before they occur. Doctors would also have warning signs about possible deterioration of their patients' health.

These developments are shifting the focus from mass production to mass customisation. They promise significant cost savings for patients and the healthcare system by preventing complications and optimising treatment timing, as well as reducing unnecessary clinic visits and enabling early intervention when needed.



# Closing the neural loop with AI

Artificial intelligence and machine learning are transforming the field of medical bionics. Researchers in medical bionics design are creating devices such as bionic eyes and ears, and implants that interface with the body's brain, spinal cord and a complex network of nerves.

The cochlear implant is an open-loop bionic ear system that was developed by Professor Graeme Clark and his team at the University of Melbourne in 1978. It is a one-way communication system that takes external sounds and uses electronic stimulation to transmit them to the brain without taking into consideration the brain's response.

Progressing from this 'open-loop' approach, University of Melbourne researchers in medical bionics today are using AI to pivot to a 'closed loop' approach developing agile devices that can record, interpret and react to the multiplicity of signals the body sends.

This research is unlocking the full potential of these devices to not only enhance their ability to interact with the brain but also deepen our understanding of how the brain works. These implants are less invasive under-scalp devices instead of the current neural devices that require major high-risk surgery to be implanted.

One device that is tackling these challenges at once is the Stentrode™, developed by Professor Tom Oxley at the University of Melbourne in partnership with the Royal Melbourne Hospital and the Florey Institute of Neuroscience and Mental Health. The Stentrode is close to becoming the world's first commercially available implantable brain-computer interface.

It is a minimally invasive device that involves inserting a tiny electrode into the brain's blood vessel near the motor cortex. This enables people with paralysis to use their brain to control their mouse and type on a computer.

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This device has life-changing potential, giving people with motor neurone disease (MND), Parkinson's disease, spinal cord injury and other conditions unprecedented independence to use smart devices and communicate. More than 30 million people globally currently experience paralysis and associated conditions.

Professor Tom Oxley and the University of Melbourne patented the device and are commercialising it through Synchron, a New York-based company, which has received substantial investment and has just partnered with Apple. The Stentrode has been successfully inserted in patients' brains.

The University's researchers are working on several other projects with the potential to improve people's quality of life. The Minder is a device developed and commercialised by Epiminder that has received US Federal Drug Administration (FDA) approval. Based on research conducted by Professor Mark Cook and Professor David Grayden in partnership with the Bionics Institute and St Vincent's Hospital in Melbourne, it's an epilepsy monitoring device inserted under the scalp that tracks brain activity and provides patients with information about their seizures.

People with epilepsy often cannot work or drive because of the unpredictability of their condition. Devices with long-term neural monitoring capabilities, such as Minder, previously thought impossible, could benefit 50 million people globally who are living with epilepsy by helping to forecast their seizure risk.

Professor Grayden's team has also made promising progress in the emerging research area of electroceuticals, which uses electrical stimulation of body systems from an implantable device to mimic the therapeutic effect of chemical compounds. Researchers at the University of Melbourne, the Bionics Institute, the Florey Institute of

Neuroscience and Mental Health and Austin Health have identified specific nerve activity patterns associated with gut inflammation, and by electrically stimulating intestinal nerves could potentially treat inflammatory conditions such as Crohn's disease.

Integrating AI into research programs represents another important innovation. Professor Grayden directs the ARC Training Centre in Cognitive Computing for Medical Technologies, which uses machine learning to manage massive datasets from neural recording and other systems.



# Advancing neurological repair

Titanium, silicon and stainless steel are often used by surgeons to repair the body. After healing, a second invasive procedure is needed to remove screws or a scaffold, increasing the risk of infection.

Biomaterials and regenerative medicine are changing this. Combining engineering research in material science, stem cells and neuroscience, researchers at the University of Melbourne have created smart scaffolds that can guide the brain to regenerate damaged tissue and even target drug delivery to precise locations. These patented discoveries have clinical applications in Parkinson's disease, stroke and other neurodegenerative diseases.

One significant hurdle is designing materials that precisely mimic the brain's mechanical and biochemical environment. Another critical issue, especially in large cell transplantations, is overcoming the lack of robust vascularisation – the process of growing blood vessels into a tissue to improve oxygen and nutrient supply.

Insufficient nutrients and oxygen can lead to a necrotic core, a central area of dead tissue. Controlling the body's immune response to transplanted materials and ensuring the proper scaling and standardisation of cell for regeneration are also ongoing challenges.

Professor David Nisbet and his team are developing innovative solutions to these problems. They have registered five patents and made significant strides in designing biomaterials that accurately mimic brain tissue by creating protein-inspired hydrogels.

These advanced biomaterials, primarily water-based hydrogels composed of small amounts of polymer and peptide or amino acid sequences, guide cellular responses. They also spontaneously assemble, transition from liquid to solid after injection, and naturally biodegrade once their scaffolding role is complete, eliminating the need for surgical removal.

In a breakthrough, Professor Nisbet's team has engineered these hydrogels to release oxygen at specific rates, sustaining the cells until new blood vessels form. The researchers were inspired by sperm whales. These animals dive to great depths and have efficient myoglobin – a protein found in muscles – that helps them obtain the oxygen they need to keep moving. The team created a synthetic variant of sperm whale myoglobin and incorporated it into the hydrogel.

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human trials, offering hope for stroke patients, and people with Parkinson's and other neurological diseases. If successful, instead of merely managing their symptoms, diseases could be modified and people could even make a functional recovery.

Other projects focus on eliminating unwanted cells within transplants, enriching for the most therapeutically effective cell populations to enhance regeneration, and modulating the immune response to prevent chronic inflammation.

Looking ahead to the next decade, research in biomaterials and regenerative medicine is trending towards intelligent, dynamic biomaterials. Researchers are engineering materials to sense environmental cues such as pH, temperature and enzyme activity.

These next-generation materials would also be able to release drugs autonomously, alter their stiffness or release biological molecules to precisely guide cell behaviour. Professor Nisbet's group is already incorporating machine learning and computational modelling to predict protein modifications for desired oxygen release and movement.

The regenerative medicine market is currently experiencing exponential growth, attracting numerous start-ups and strategic partnerships. Focus is shifting towards off-the-shelf therapies that are standardised, consistent and scalable, allowing clinicians to easily combine them with cells for a plug-and-play system.

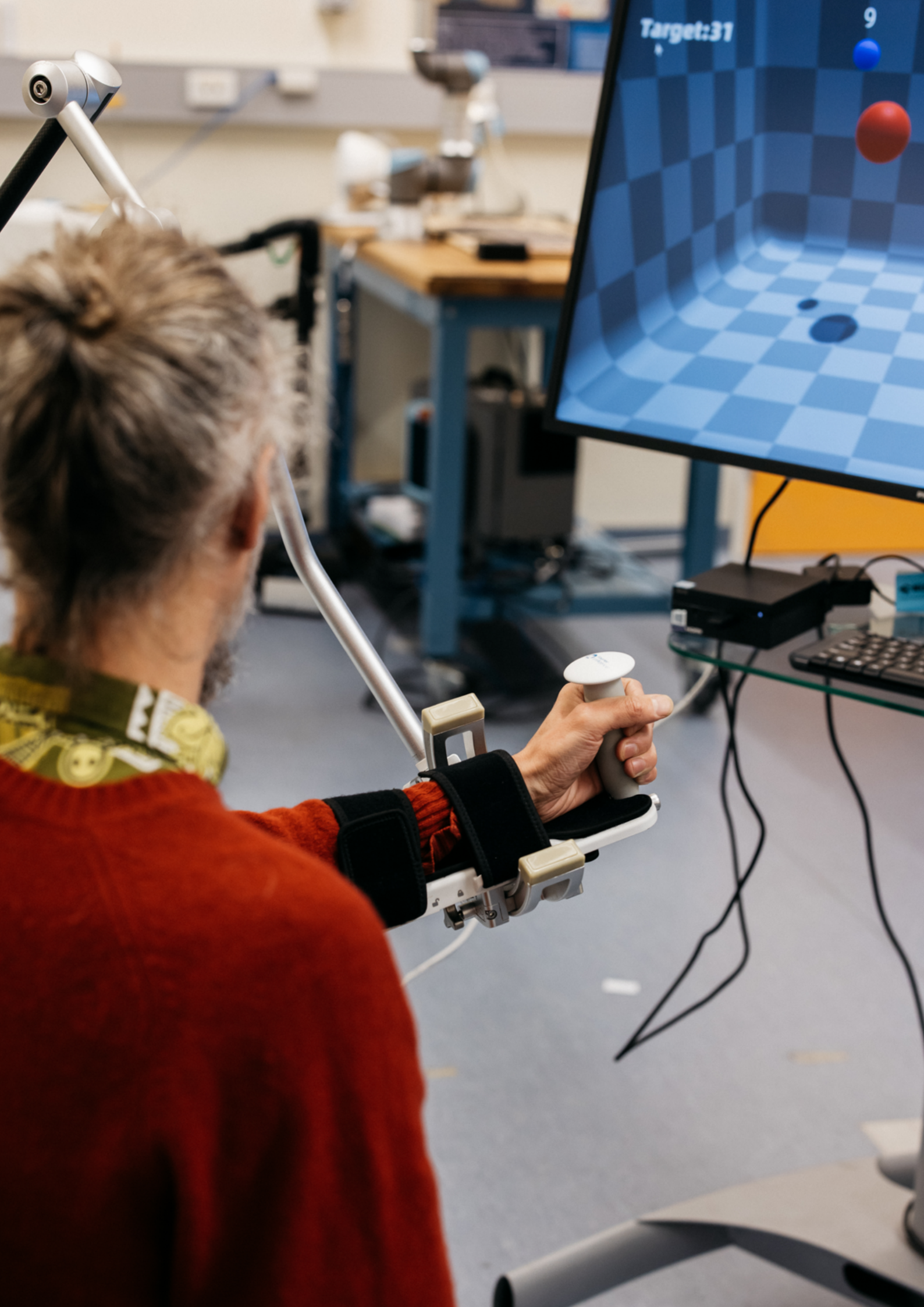
# Industry collaboration lifeline

Realising this MedTech vision of personalised and preventative healthcare requires collaboration between research institutions, medical technology companies, pharmaceutical firms and healthcare providers.

A significant trend is the commercialisation of research as early as possible to ensure these life-changing technologies become accessible to patients as soon as possible. The University of Melbourne is fostering an environment that supports this transition from research to industry.

Wider industry engagement is critical and will determine whether these innovations reach patients within five years rather than 10. This engagement represents more than technological advancement – it offers hope for families facing the devastating impacts of chronic disease, where prediction, early detection or personalised treatment could prevent the severe life limitations that currently affect millions of patients and their loved ones worldwide.

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