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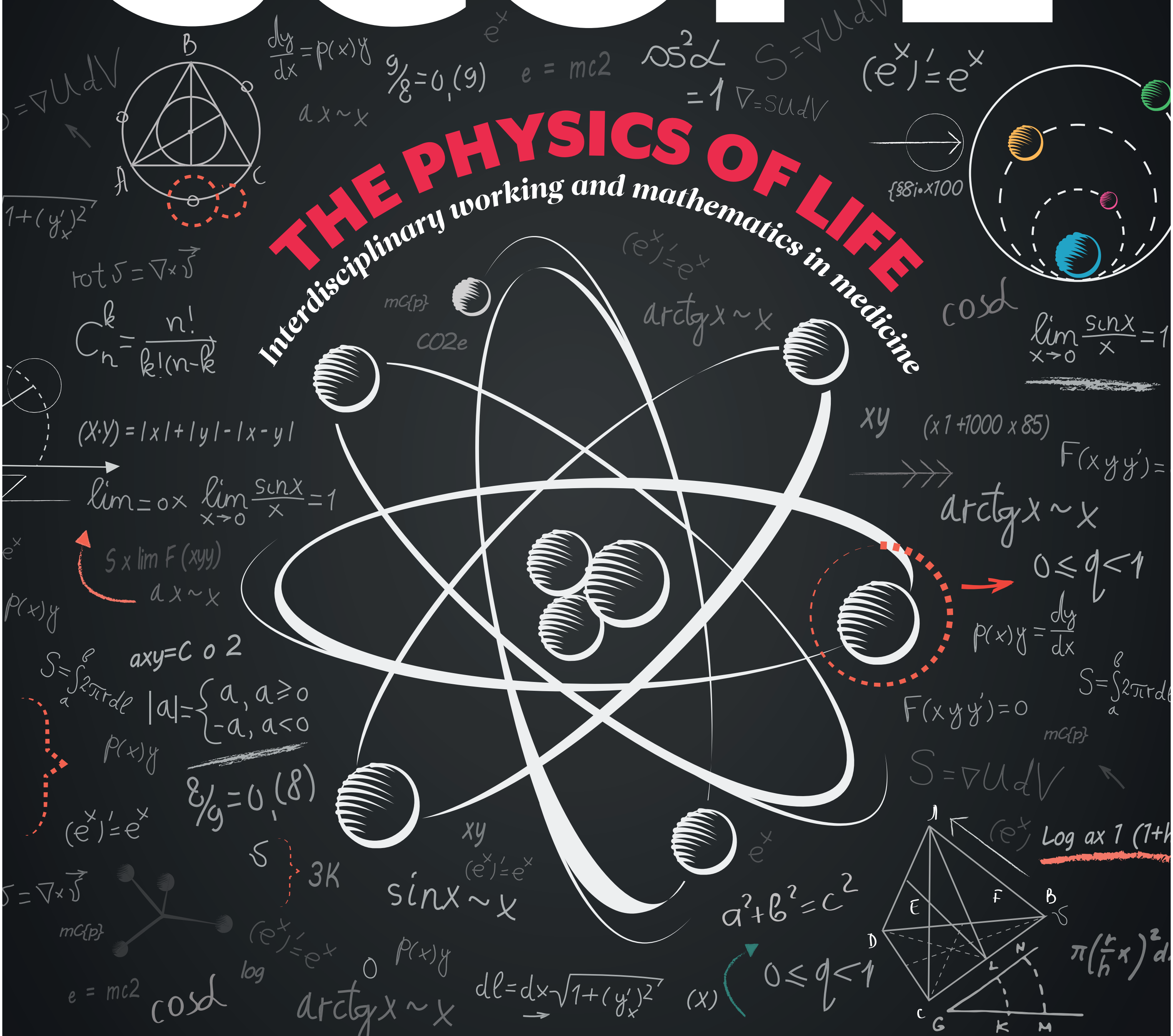
Volume 31 | Issue 1 | Spring 2021

IPEM Institute of Physics and Engineering in Medicine

SCOPE

THE PHYSICS OF LIFE

Interdisciplinary working and mathematics in medicine



TECHNOLOGY

Knowledge or study as opposed to equipment, machines and tools

THE CLIMATE CRISIS

IPEM members form an Environmental Sustainability Group

ALL AT SEA

Radiation protection advice enables military radiography

WEARABLES

The potential role of wearables in health monitoring is changing

CHAIR OF IPEM SCOPE EDITORIAL ADVISORY BOARD

Showcase your work

Usman Lula outlines recent *Scope* magazine developments and how IPEM members can contribute to and help shape the publication.

Welcome all to our first feature-packed issue of 2021 – the year when coronavirus vaccines will hopefully save lives, relieve the health service and return us to our once-cherished freedom!

The *Scope* Editorial Advisory Board (EAB) exists to support a number of developments, including the commissioning of new features. We are trying to balance areas represented by IPEM and, in doing so, may not always receive features from every area. For this reason, in preparation for the next issue, we hope to approach authors from areas that are less represented in *Scope* magazine.

We also plan to re-introduce themes to *Scope* in one or two issues per year, starting with the June 2021, when we plan to cover the use of artificial intelligence and deep learning for patient and science benefit. This applies to all areas represented by IPEM, so if you would like to showcase your work, please do get in touch.

This issue really is jam-packed – from a novel breast technique in radiotherapy and what radiation protection advice looks like in military radiography, to the use of wearables in health monitoring. I hope you enjoy the features as much as I have! You may notice that in this issue we haven't included a Big Debate section. Instead, we have an interesting perspective on the previous issue's Big Debate question around technology, kindly supplied by Ste Lake (Liverpool University Hospitals NHS Foundation Trust).

> To develop *Scope* further, we need your feedback to understand your requirements for our magazine

To develop *Scope* further, we need your feedback to understand your requirements for our magazine. Our *Scope* readership survey is live now, so please let us know what you think by visiting **bit.ly/3b1c6Ui**.

Just for reference, I would like to remind the readership that there are three strategic areas of development for *Scope* (see the box, below).

We have two vacant positions at the *Scope* Editorial Advisory Board – a Clinical & Biomedical Engineering Commissioning Editor, and an Applied Academic Commissioning Editor. If you are interested in either role, please contact me directly, or via the IPEM national office.

Finally, I'd like to thank our readership for supplying us features for *Scope* magazine. Without your contributions, *Scope* would not be where it is today! Thanks once again…

Enjoy the read and stay safe.

Usman Lula

Usman Lula
Chair of IPEM *Scope* EAB

REVAMP

Strategic development

DESIGN – the magazine has had an excellent revamp since the move to the new publisher. Initial reader feedback has been generally positive, though we will know more following the *Scope* reader survey.

CONTENTS – in order to make the magazine more visually dynamic and engaging, the number of articles in *Scope* has reduced and more regular features have been added. There is a focus on balancing content for all areas represented by IPEM and integrating themes at certain points during the year. The 'Debates' section seems to have been a success, though, once again, we will know more on this after the *Scope* survey.

ENGAGEMENT – although the readership is engaging with the topics using the IPEM platform, there is still much development to undertake in this area. Paul Barrett (IPEM Senior Communications Manager) has recently informed us that he will be the main contact person for the *Scope* EAB at the IPEM National Office – and I am both hopeful and excited that we can further improve the reader engagement.

IPEM Institute of Physics and Engineering in Medicine

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bit.ly/2SRhh0E

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> The best models become an element in a cyclical exchange between theory and experiment.

– *Dr Adam Gibson* page 14

UPFRONT

Cover image by ISTOCK

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UPFRONT

MEDICAL IMAGING

Whole body imaging – treatment initiated earlier

IMAGE: ISTOCK

Researchers from King's College London have shown that whole body magnetic resonance imaging (WBMRI) not only detects more myeloma-defining disease than positron emission tomography/computed tomography (PET/CT) with 18F-fluorodeoxyglucose (FDG), but that it also allows critical treatment to be initiated earlier.

In a study published in January, researchers looked at 46 patients with suspected myeloma, a debilitating bone marrow cancer which sees 140,000 new cases each year globally.

Less than 50% of patients survive after five years and, at present, it is not clear which is the best imaging test to use.

Lead researcher Professor Vicky Goh from King's College London said WBMRI is the most sensitive test for bone marrow infiltration by myeloma compared to PET/CT or CT alone, as this type of imaging shows up different processes within the skeleton.

"Our results showed that imaging with WBMRI changed how patients would have been managed by their doctors in 24% of cases, where review of clinical data alone would have resulted in surveillance only.

> What this ultimately means for patients is improved outcomes from earlier treatment

"What this ultimately means for patients is improved outcomes from earlier treatment.

"WBMRI resulted in a decision-to-treat in an additional 7% of patients, compared with PET/CT."

Professor Goh said that WBMRI and PET/CT only agreed on a positive diagnosis of myeloma in 59% of patients.

Just under half of the patients did not have FDG-avid disease and would have been undetected by PET alone.

Professor Goh said the study supports national guidance for improving healthcare distributed by The National Institute for Health and Care Excellence (NICE) that WBMRI should be performed as a first-line imaging test for suspected myeloma.

"Earlier diagnosis and treatment is key to improving patient outcome. Forty percent of NHS hospitals still only perform X-rays, an insensitive test, for diagnosing bone disease in suspected myeloma. This clearly needs to change."

bit.ly/3sMFDc8

FAST FACTS

46
The number of patients with suspected myeloma included in the study

24%
of cases imaging with WBMRI changed how patients would have been managed

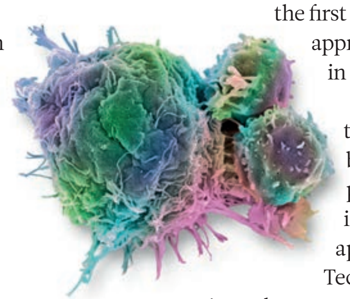
7%
WBMRI resulted in a decision-to-treat in an additional 7% of patients.

PERSONALISED MEDICINE

New personalised therapy for lymphoma

NHS clinicians in England will be among the first to offer a cutting-edge personalised cancer treatment to some people with lymphoma, after the chimeric antigen receptor T (CAR T) cell therapy was approved.

The therapy, called Tecartus, is an immune-boosting treatment that engineers a patient's own immune cells to kill their cancer. It has been recommended by the National Institute for Health and Care Excellence (NICE) for people with a rare type of non-Hodgkin lymphoma.



Tecartus takes a person's immune cells and alters them in a lab to recognise and attack cancer cells, before infusing them back into the bloodstream.

It's one of a number of CAR T cell therapies that have been developed, the first of which was approved for NHS use in England in 2018.

The decision means that more patients can benefit from this personalised immunotherapy approach.

Tecartus will be an option when someone's cancer has stopped responding to their current therapy, or who has experienced a relapse after being treated with an existing group of targeted therapies.

bit.ly/2Y3lr7T

BREXIT

NEW MEDICAL DEVICE INFORMATION SYSTEM

The UK has introduced a new medical device information system (MDIS) following its departure from the EU.

It requires that all medical devices available on the UK market to be registered with the Medicines and Healthcare products Regulatory Agency (MHRA) using official global medical device nomenclature.

The new system came into effect on 1 January 2021, with certain devices allowed a grace period for registration.

The dedication to an international identification standard is hoped to enable the accelerated adoption of new devices, ensure better support in medical decision-making and maintain high safety standards.

The MDIS database will be accessible to the public, hospitals and suppliers and is predicted to be of value for epidemiological studies.

In order to register a device with the MHRA, it must be manufactured in the UK or Northern Ireland or have an appointed UK Responsible Person with a registered business in the UK. Class I medical devices, custom-made devices and IVDs are required to register immediately, with other devices awarded a grace period until either 1 May or 1 September 2021.

bit.ly/3qDYGU5

NEWS IN BRIEF

Innovation centre

Nottingham Trent University's £23m Medical Technologies Innovation Facility has been completed. It will bring organisations and clinicians together with university researchers to develop their ideas and get them to market as quickly as possible. It will focus on supporting the development of innovative products and advanced materials.

bit.ly/3p9EWYq

Alzheimer's disease

Researchers have developed an automated method that can track the development of harmful clumps of Tau protein related to Alzheimer's disease in the brain. The automated anatomic sampling method uses PET imaging to track the presence of Tau. The team applied their technique to 443 adult participants – including 55 patients with Alzheimer's – and discovered that Tau deposits first emerged in the rhinal cortex independently from amyloid-beta before spreading to the temporal neocortex.

bit.ly/3nYOaVW

SARS-CoV-2 genomes

A team of researchers from the Istituto Superiore di Sanita in Italy, report an open-source platform-independent tool for building SARS-CoV-2 genomes from raw sequencing reads. The tool can be used without any extra hardware or software and can be run using any browser from a desktop or mobile. The teams has published their preliminary not-yet peer-reviewed paper on *bioRxiv*.

bit.ly/3a7nq0H

ALGORITHMS

Deep learning to identify gene regulation

Scientists at the University of California (UCI) have developed a new deep-learning framework that predicts gene regulation at the single-cell level.

Deep learning has revolutionised applications such as image interpretation, natural language processing and autonomous driving.

UCI researchers describe how it can also be successfully used to observe gene regulation at the cellular level.

Co-author Xiaohui Xie said the framework enables the study of transcription factor (TF) binding at the cellular level, which was previously impossible due to the intrinsic noise and sparsity of single-cell data.

A transcription factor is a protein that controls the translation of genetic information from DNA to ribonucleic acid; TFs regulate genes to ensure they're expressed in proper sequence and at the right time in cells.

By training a neural network on large-scale genomic and epigenetic datasets, the researchers were able to identify novel gene regulations for individual cells or cell types.

bit.ly/2LVPeN8

UP CLOSE

FEDERATED LEARNING

WHAT IS FEDERATED LEARNING?

It is a technique that trains an algorithm across multiple devices or servers holding local data samples, but avoids clinical data aggregation, which is undesirable for reasons including patient privacy issues

WHAT IS THE LATEST?

Mount Sinai researchers have published one of the first studies using a machine federated learning to examine electronic health records to better predict how COVID-19 patients will progress.

TELL ME ABOUT THEIR STUDY?

Using data from electronic health records at five hospitals to predict mortality in COVID-19 patients, they compared the performance of a federated model against ones built using data from each hospital separately, referred to as local models.

WHAT DID THEY FIND?

After training their models on a federated network and testing the data of local models at each hospital, the researchers found the federated models demonstrated enhanced predictive power and outperformed local models at most of the hospitals.

WHAT DID THE AUTHORS SAY?

Assistant Professor Benjamin Glicksberg said: "Federated learning is gaining traction within the biomedical space as a way for models to learn from many sources without exposing any sensitive patient data. In our work, we demonstrate that this strategy can be particularly useful in situations like COVID-19."

bit.ly/3o6NaIS

IMAGE: ISTOCK / SPL / HENRY BROTHERS

NEGATIVE PRESSURE VENTILATION

NEW "IRON LUNG" VENTILATORS

A new negative pressure ventilation assistance device looks set to go into mass production and could be available on NHS wards this year, it is claimed.

The non-invasive Marshall Exovent-19 prototype negative pressure ventilation assistance device was developed to provide additional treatment options for any patient with respiratory failure, including those with COVID-19.

It offers the benefit of greater patient comfort as they don't need to be asleep or have an artificial airway.

The team behind the project began work on it last year in response to fears the UK and other countries could run out of ventilators because of the demand from patients with COVID-19.

The Exovent has yet to be investigated through a full clinical trial, but it has been tested by several NHS hospitals

The team is due to submit a bid to the Medicines and Healthcare products Regulatory Agency and hopes to get approval within a matter of months.

bit.ly/3o3CmSf

CLINICAL ENGINEERING

TEXT APP TO HELP MEDICAL STAFF COMMUNICATE

Addenbrooke's Hospital, Cambridge, has carried out tests of a speech app as a way of helping its medical team communicate with people who are deaf or have hearing loss, when mouths are covered.

The free speech-to-text app, called Live Transcribe and Sound Notifications, aims to help people to more easily follow and understand what is said when both parties are wearing face coverings and personal protective equipment (PPE).

The clinical engineering team at Cambridge University Hospitals NHS Trust had started to develop prototype clear masks. However, they remained keen to explore alternative solutions that may have been quicker to implement.

Then a product development and engineering consultancy came up with the solution of using a transcription app on a low-cost Android smartphone or Android smartwatch.

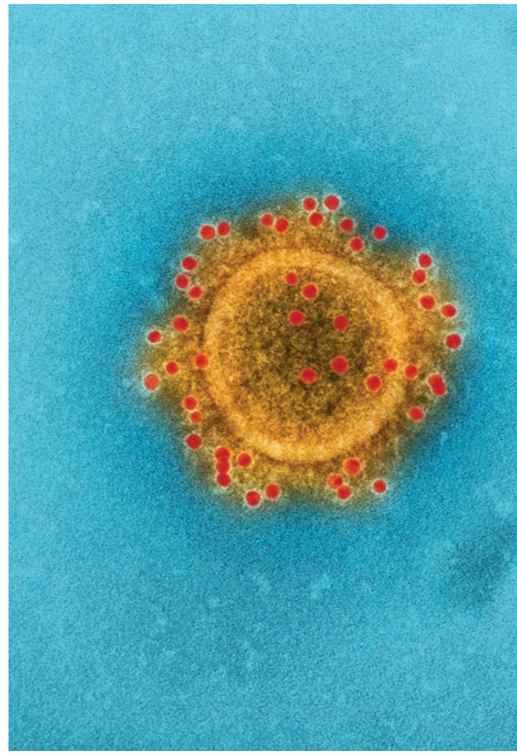
The phone could be worn either on the user's lapel or kept visible on the forearm using a sports arm strap.

The app, which is free to download, automatically transcribes text in near-real time, and can be enlarged on the screen so it is easily read, and custom words – such as specialist medical terms – can be added into the dictionary if required. Google's app development were also contacted to verify that conversations processed on their servers are not recorded or stored.

bit.ly/3j5aXyx

BIOENGINEERIING

Universal vaccine platform



Scientists have developed a bioengineered bacteriophage T4 nanoparticle structure using clustered regularly interspaced short palindromic repeats (CRISPR) technology that can be used as a universal platform to produce vaccines.

They used SARS-CoV-2 as a model to develop the platform, which they say can be used to rapidly produce vaccine candidates comprising multiple components of any emerging pathogen.

The scientists used bacteriophage T4 as a model platform to design vaccine candidates. The capsid of T4 is coated with two nonessential proteins, namely Soc and Hoc. While Soc helps stabilise the capsid, Hoc helps T4 to attach to host cells. These two proteins can be used as adaptors to adhere antigenic determinants (epitope) to the capsid. Mechanistically, the T4 capsid decorated with viral/bacterial epitopes acts as pathogen-associated molecular patterns, and thus can trigger the activation of pattern recognition receptors and induce strong immune responses.

A preliminary scientific report, which has not yet been peer-reviewed, is currently available on *bioRxiv*.

The study outlines a T4 phage-based vaccine designing platform that can generate efficient vaccine candidates within a very short period.

bit.ly/2Y0WwB

SCREENING

TEMPERATURE SCANNERS "UNRELIABLE" FOR COVID-19

Using temperature scanners can result in a large number of false negatives, allowing people with COVID-19 to pass through hospitals undetected, it is claimed.

A new study argues that taking temperature readings of a person's fingertip and eye would give a significantly better and more reliable reading and help identify those with fever.

The study is co-led by human physiologist and an expert in temperature regulation, Professor Mike Tipton. He said: "If scanners are not giving an accurate reading, we run the risk of falsely excluding people from places they may want, or need, to go, and we also risk allowing people with the virus to spread the undetected infection they have."

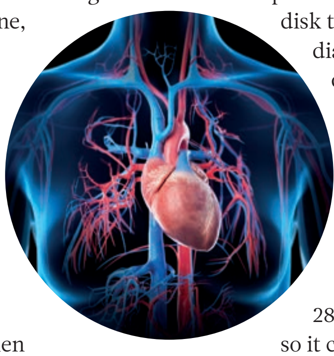
The researchers report four key factors:

MECHANO-ACOUSTIC SENSOR

Wearable cardio-respiratory monitoring

A highly sensitive wearable sensor for cardiorespiratory monitoring could potentially be worn continuously by cardiac patients or others who require constant monitoring.

The small sensor is based on an electrochemical system involving two ionic forms of iodine, I^- and I_3^-.



A solution containing these electrolyte substances is placed into a small circular cavity that is capped with a thin flexible diaphragm, allowing detection of subtle movements when placed on a patient's chest.

Small motions that arise from the heartbeat and breathing cause the flexible diaphragm to move the I^-/I_3^- solution into a narrow channel in the device, where it is electrochemically detected by four platinum electrodes.

The investigators created a mould for the circular chamber and the associated narrow channel using 3D printing. A solution to create Ecoflex 00-20 was poured into the mould to form the body of the sensor and was also spin-coated on a rapidly rotating disk to produce the thin diaphragm. After the diaphragm and chamber body were bonded together, the investigators used a syringe to fill the chamber with the electrolyte solution.

The resulting device is 28mm wide and is skin-safe, so it can be attached directly to the patient's body. The device was able to detect the heartbeat with high sensitivity. A signal-to-noise ratio of greater than 6:1 was achieved, which is considered good.

bit.ly/3iBTId9

IMAGES: GETTY / ISTOCK / ALAMY

1. Temperature alone isn't a good indicator of disease – not all who have the virus have a fever and many who do, develop one only after admission to hospital.

2. Measuring skin temperature doesn't give an accurate estimation of deep body temperature (raised in a fever). A direct measure of deep body temperature is impractical;

3. A high temperature does not mean a person has COVID-19.

4. Taking two temperature measurements, one of the finger, the other of the eye, is likely to be a better and more reliable indicator of a fever-induced increase in deep body temperature.

The researchers say a significant proportion (at least 11 %) of those with COVID-19 do not have a fever, and that fewer than half those admitted to hospital with suspected COVID-19 had a fever.

Although the majority of positive cases go on to develop a high temperature after being admitted to hospital, they were infectious before their temperature increased.

bit.ly/2Mby0eA

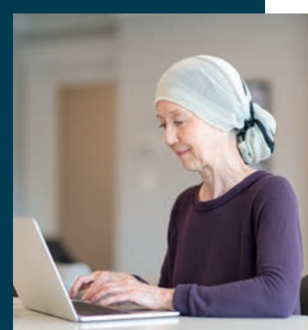
ONCOLOGY

Algorithms to manage cancer

Hundreds of cancer patients have used computer algorithms to manage their symptoms and improve their wellbeing in a unique UK trial.

The early stage colorectal, breast or gynecological cancer patients took part in the trial of the eRAPID system, developed by the University of Leeds, which allowed them to report online symptoms from home and receive instant advice on whether to self-manage or seek medical attention. Patients reported better symptom control and physical wellbeing in the early weeks of treatment, with the system preventing symptom deterioration in about nine percent of patients after 12 weeks.

Those behind the study claim it demonstrate that improvements to patients' physical wellbeing can be achieved in a cost-effective way without increasing clinicians' workload.



It is the first such trials to offer automated advice, and one of only a few to focus primarily on early-stage patients whose treatment aims to cure the cancer.

Programme lead Professor Galina Velikova said: "Rising numbers of cancer patients are receiving a range of anti-cancer treatments which means patients are living longer and require longer periods of care and monitoring.

"Remote online monitoring options have the potential to be a patient-centred, safe and effective approach to treatment and manage the growing clinical workload for cancer care."

bit.ly/2Y1m2GX

EXTERNAL RELATIONS MANAGER

Shaping policy

Sean Edmunds, the Institute's External Relations Manager, summarises some of the ways members and officers continue to help shape policy across the UK on behalf of IPEM.

Back in the autumn, the Government launched its Comprehensive Spending Review and IPEM submitted a response to this.

The submission called for action to be taken with regards to addressing workforce shortages, investment in equipment, and investment in the IT infrastructure of the NHS. The main points IPEM made were:

- Asking the Government to redress the deficit in the Medical Physics and Clinical Engineering (MPCE) workforce in terms of funding shortfalls and workforce shortages. This was calculated to require investment of £37m for the radiotherapy physics workforce, and approximately £22m for other MPCE workforces
- Investment in equipment, including £140m to replace out-of-date linear accelerator machines that are more than 10 years old, and other equipment including MRI and CT scanners, in order to support future healthcare needs.

IPEM also joined forces with the Royal College of Radiologists and the Society and College of Radiographers for a joint submission on the spending review. You can read the IPEM submission in full by visiting the website at News & External Affairs > Consultations.

In his response to the Spending Review, Chancellor Rishi Sunak promised £3bn extra to the NHS in England, with £325m earmarked for expanding diagnostic testing, including the replacement of old scanners.

While IPEM President Professor Stephen O'Connor welcomed the announcement, he said new facilities must be delivered with new equipment and there was a clear need for a well-trained and appropriately staffed workforce, together with new healthcare delivery models to ensure early diagnosis, better prognosis and optimised patient outcomes.

There was a clear need for a well-trained and appropriately staffed workforce

Also in the autumn, IPEM signed a new Memorandum of Understanding (MoU) with the American Board of Magnetic Resonance Safety (ABMRS). This was another step forward in shaping the progress of Magnetic Resonance Safety Expert (MRSE) certification in the UK. The MoU set out the relationship between IPEM and the ABMRS with regards to the ABMRS

THE SCIENTIST TRAINING PROGRAMME

A joint letter from IPEM's Lead Station Writers, IPEM's President and the Director of the Professional and Standards Council was sent to the National School of Healthcare Science about changes to the Scientist Training Programme which affected those in their third year in 2020.

The UK-wide restrictions that have been brought about by COVID-19 meant that the National School had to make decisions to ensure students would not be adversely affected by the reduction in trainer availability and cancellation of the 2020 OSFA examinations.

The letter to Professor Berne Ferry, Head of the National School, expressed concerns that changes had been made without consulting with the Physical Sciences Theme Board.

Assurances were sought that the Independent Assessment of Clinical Competence, as a temporary alternative to Objective Structured Final Assessment, would not be used after the resits for the third year cohort.

MRSE exams which are held in the UK.

Following the signing of the MoU, the Institute launched the MRSE Certificate of Competence, which is due to open to applicants this spring/early summer. The certification model that IPEM has adopted requires both knowledge and experience. The knowledge is demonstrated by successfully completing the ABMRS MRSE exam. The MR experience of an applicant is assessed from a structured portfolio demonstrating a broad range of MRSE activities.

IPEM was asked to provide professional body input into the NHS Supply Chain tender specification minimum standards for the NHS catalogue. The supply challenges presented by the COVID-19 pandemic surge response demonstrated the need for expert input and involvement.

The Institute's relevant Special Interest Groups looked at equipment needs in their area, and the Vice President for Medical Physics, Matt Dunn, Head of Radiation Physics at Nottingham University Hospitals NHS Trust, led on responding to the NHS Supply Chain team.

Statutory regulation

The demands placed on the UK's health infrastructure by COVID-19 also highlighted the need for clinical technologists to become registered professionals. IPEM, together with the British Nuclear Medicine Society, the Register of Clinical Technologists and other bodies, continued to make the case that statutory registration would help deliver better patient outcomes and optimise service delivery.

Representations were made to the Health and Social Care Select Committee about this and a number of parliamentary questions were asked of the Secretary of State for Health and Social Care, including what assessment had been made about the potential merits of statutory regulation, and if there were plans to extend the professional registration of healthcare staff on the Health and Care Professions Council (HCPC) register beyond those currently listed.

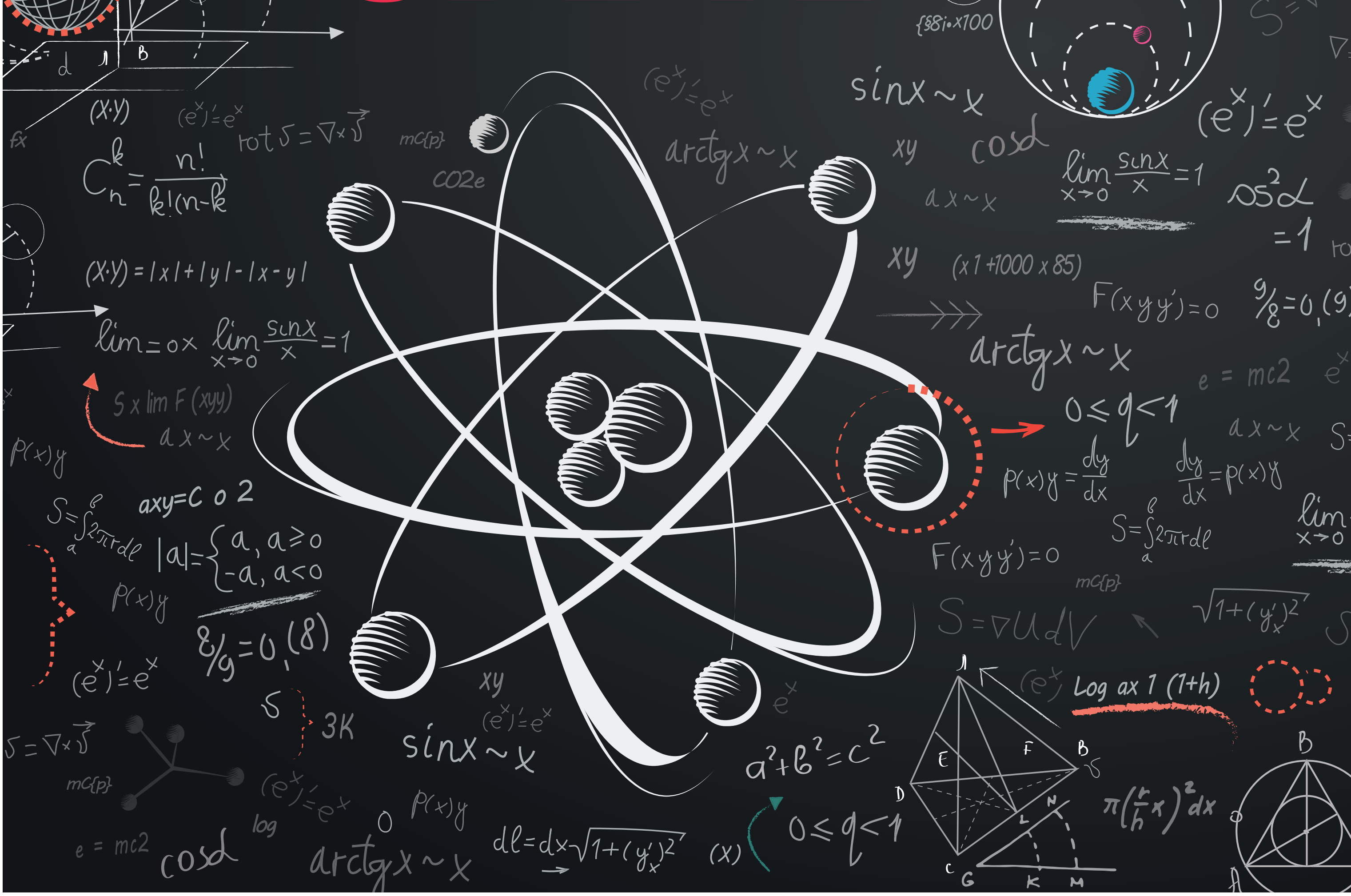
Professor O'Connor commented that while the Government said there were currently no plans to extend the list of professions regulated by the HCPC, IPEM, together with other bodies; would continue to press the case for the statutory registration of all clinical technologists.

> **NEW FACILITIES MUST BE DELIVERED WITH NEW EQUIPMENT**

IMAGE: ISTOCK

THE PHYSICS OF LIFE

What impact can interdisciplinary working and mathematics in medicine have on healthcare? **Professor Stephen Smye** and colleagues look at the issues.



Medical physicists and engineers play a vital role in bridging the gap between clinical medicine, and the mathematical and physical sciences. This role is becoming even more important as it is widely recognised that the "grand challenges" in medicine cannot be addressed successfully by single disciplines. This article is intended to encourage active engagement by the medical physics and engineering community in this fast-developing interdisciplinary area, with a particular emphasis on the role of mathematics in medicine.

Given the increasing availability of large amounts of data based on careful measurement in biology and medicine, can we now draw useful lessons for the development of medicine from noting how physics has developed historically? Is there now a "Physics of Life" which reflects converging scientific approaches? Can mathematical theory, a distinctive characteristic of physics, accelerate the pace of medical advances?

Mathematical models in physics

The recent discovery of the Higgs Boson illustrates the central role that mathematical models – theories – play in physics. Whilst the Higgs Boson was confirmed experimentally at the Large Hadron Collider in 2013, it was predicted by Peter Higgs and colleagues from the mathematical theory of sub-atomic particles in 1964. The 2013 Nobel prize was awarded to Higgs and Englert "for the theoretical discovery of a mechanism that contributes to our understanding of the origin of mass of subatomic particles, and which recently was confirmed through the discovery of the predicted fundamental particle, by the ATLAS and CMS experiments at CERN's Large Hadron Collider".

IMAGES: ISTOCK

Here, we distinguish between mathematical models and statistical models. By "statistical models" we mean those that determine numerical relationships between data sets, but without reference to any underlying mechanism. In contrast, by "mathematical models", we mean those models that exploit our understanding of a physical or biological mechanism. Much of modern physics is built on mathematical models, posing the question "Could predictive mathematical models become commonplace in medicine?" Some areas of medicine, such as epidemiology and radiotherapy treatment planning, already have a long and distinguished track record of mathematical modelling. It may well be that this aspect of physics will make an even greater impact on medicine than the well-established role that physics has played in the development of medical technologies.

> "CAN MATHEMATICAL THEORY ACCELERATE THE PACE OF MEDICAL ADVANCES?

A good mathematical model is as simple as possible while being consistent with the data. This reduces the chance of overfitting. It should also make predictions about how the system would behave under a range of different conditions. Models which simply describe observed behaviours are not informative. The best models become an element in a cyclical exchange between theory and experiment, where experimental data is described by a candidate model capable of predicting the data which should be observed under a different set of experimental conditions. Depending on the outcome of the set of experiments suggested by the model, adjustments are then made to the model and the process of testing repeated.

These aspects of model building – simplicity, predictive power and iterative testing by experiment – are now illustrated by several examples.

Mathematics in the clinic

The international Physiome project attempts to provide a comprehensive, multi-scale mathematical model of physiological dynamics and functional behaviour of the human body – a virtual human – and is a particularly ambitious example of predictive clinically-informative mathematical modelling. The Physiome project builds on previous work, including extensive work developing mathematical models of the electrophysiology of the heart which have been used, for example, to optimise anti-arrhythmia therapy. The model enables a wide range of different conditions and treatments to be readily simulated.

The Moffitt Cancer Centre in the US has an extensive and established research programme in mathematical oncology which it is now extending to the selection of treatment strategies for chemotherapy and targeted therapies. Some models, based on the evolutionary dynamics of tumours, have led to some novel hypotheses, for example identifying and modelling intra-tumoural sub-populations based on their adaptive strategies rather than their molecular properties. This has allowed potential therapeutic interventions (for example, manipulation of pH local to the tumour) to be identified, which steer the tumour development into a less invasive phenotype.

The goal of mathematical medicine is to create predictive, patient-specific mathematical models (PSMs), based on a detailed mechanistic description of disease (rather than simply a statistical model) which draw on large and disparate patient data sets. Such models could then be used to simulate the impact of different treatment regimes and to suggest optimal personalised treatments. These models could be refined by drawing on data from regular monitoring of the patient. A review visit to the diabetes clinic, for example, might include reference to a PSM based on the patient's blood glucose measurements logged over the previous year accompanied by clinical data provided by wearable technology. The PSM could suggest adjustments to the treatment regime, which would in turn lead to an adjustment of the PSM.

New biology and medicine will need new mathematics or, rather, new applications of existing mathematics. A good example of this is the application of network (or graph) theory which was developed in its original form by pure mathematicians who were not originally motivated by real-world applications. Network theory describes how networks of interacting objects behave as a whole system. Unsurprisingly, given that biology and society are characterised by networks, this branch of mathematics is now contributing significantly to our understanding of many areas, including genomics, proteomics, cellular physiology and public health.

"NEW BIOLOGY AND MEDICINE WILL NEED NEW APPLICATIONS OF EXISTING MATHEMATICS

FURTHER READING

- The international Physiome project: **bit.ly/36oflU6**
- The Physics of Life Network: **bit.ly/3iVxzS0**
- Cancer Research UK's multi-disciplinary award scheme: **bit.ly/3t2pmA9**
- UKRI interdisciplinary fellowship schemes: **bit.ly/3pzrcpV**
- The NIHR Fellowship Programme: **bit.ly/3t7mAJl**

Barriers to model-building

The first barrier to constructing mathematical models in medicine is that biology is complex, being made up of emergent and contingent phenomena, which cannot be readily reduced to basic laws framed by mathematics. "Emergence" refers to large numbers of simple interacting objects that display collective properties which cannot be easily deduced from the behaviour of an individual entity. A pioneer in the physics of emergence is the Nobel Prize-winning physicist Philip Anderson. His article *More is Different* is highly relevant to biology. A second barrier is linked to the quality of clinical and biological data, which is often messy, compared with data available to theoretical physicists. Messy data sets are more suited to analysis by statistical techniques, including machine-learning, and require an approach to determining underlying models, such as comparing a range of different mathematical models to data using a Bayesian approach. The third barrier is cultural; it can be challenging to communicate methods that require an understanding of mathematics in an interdisciplinary forum.

Routes to engagement

Research funders, including UK Research and Innovation (UKRI) and the constituent Research Councils, Cancer Research UK, Wellcome Trust and NIHR, have created

schemes to draw in mathematicians and physicists to medical, biological and population sciences, and to help clinicians engage with other sciences. Examples of these interdisciplinary initiatives include:

- The Physics of Life Network (PoLNet3) funded by UKRI. The network in its third funding cycle was formally launched in October 2020. PoLNet3 now includes a Physics of Medicine element funded by the Rosetrees Trustand is embedded within the wider Physics of Life network. PoLNet3 is particularly keen to encourage participation by medical physicists and engineers, and membership is free.
- A "Physics of Life" approach uses theoretical and experimental physics to explain biological phenomena, adding a new dimension to traditional biophysics via physics-led rather than physics-facilitated investigations. It draws on recent advances in physics to explore open questions in living systems, such as the mechanisms of "emergent" properties. Workshops, sandpits and summer schools funded by PoLNet3 are deeply interdisciplinary and intended to address some of the "grand challenges" in biology and medicine, including antimicrobial resistance, metastasis and dementia. Recent events include the "Physics of Brains" and "Neurodegenerative disease of the Brain".
- Centres for Mathematical Sciences in Healthcare funded by the EPSRC. These Centres, based at the Universities of Cambridge, Exeter and Liverpool, and Imperial College, offer interesting opportunities for engagement by medical physics and engineering in key areas including imaging, precision healthcare, antimicrobial resistance and the management of long-term conditions.
- Cancer Research UK's Multidisciplinary Award scheme is co-funded by EPSRC and requires at least one investigator from the engineering or physical sciences.
- UKRI funds a wide range of fellowship schemes, many of which are aimed at interdisciplinary research.
- The National Institute for Health Research (NIHR) funds fellowships that are well suited to medical physicists and engineers looking to deploy their mathematical skills to important problems in healthcare.

University curricula are also responding to the need for improved training in mathematics to extend beyond the physical sciences, though there is more work to be done, not least in strengthening the teaching of mathematics in schools. However, whilst it makes little sense to expect medical students to undertake extensive training in advanced mathematics, for physicists and engineers such training is core to their training and is coupled with an appreciation of the power of mathematics to encapsulate clinical understanding. Medical physics and engineering should therefore be able to make a leading contribution to this fast-developing area.

Conclusion

The increasing convergence of physics and life, based on complementing clinical skills with mathematical insight, offers rich rewards and outstanding opportunities for medical physicists and engineers. Indeed, the mathematical model is a key component of what is increasingly recognised as "systems medicine".

In conclusion, lest anyone think that mathematical medicine will lead to an unduly narrow view of clinical practice, we end with a well-known quote from Einstein: "Not everything that counts can be counted, and not everything that can be counted counts."

ACKNOWLEDGEMENTS

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In 1953 Gray was formally appointed Nuffield Fellow and Director of the British Empire Cancer Campaign (BECC) Research unit in Radiobiology at Mount Vernon Hospital. In that year he also gave the Sylvanus Thompson Memorial Lecture at the British Institute of Radiology. Gray brought with him several of his colleagues from Hammersmith, including Oliver Scott, who assisted him in his understanding of the role of oxygen in tissues and radiation damage, which he had first looked at with John Read 20 years earlier.

Jack Boag formally joined Gray in 1954, but spent his first two years seconded to the Physics Department at St Bartholomew's Medical College working with Professor Jo Rotblat on a 15MV linear accelerator.

He wrote in his obituary of Gray: "Throughout his life Rutherford remained his ideal of a leader of scientific research, and in his own laboratory Gray set out the recreate a 'Cavendish' atmosphere... He had a boorish sense of humour and keenly appreciated the ridiculous aspects of a situation, but his jokes were never barbed and more often than not were told at his own expense."

He continued: "He was able to create the kind of group he believed to be the most effective in research

1 Chapel circa 1999

THE GRAY LABORATORY

A brief history pt. 2

Edwin GA Aird delves again into the history of the world's first radiobiological institute and takes us from 1953 to the institute's relocation in 2008.

2 Mount Vernon Hospital and The Gray Laboratory, aerial shot.

3 Louis Harold Gray (13 January 1960)

-small in number, but widely based in experience and outlook. He left his scientific staff very free to follow their own ideas but constantly stimulated and challenged them with queries and suggestions."

Gray's own research was centred on increasing the impact of radiation on tumour cells without increasing the damage of normal cells. This included on-going work studying the "oxygen effect". Gray died from a heart attack in 1965. He was just 59 years old.

Oliver Scott

Oliver Scott was appointed Director of the Lab after Gray's death in 1965. Initially, his role under Gray, who described him as a "physiologist", was to continue the animal work he began at Hammersmith.

His national service had been in the Royal Naval Volunteer Reserve where he gained experience with the use of high-pressure oxygen (HPO); this was to help him later when HPO was used in trials to understand its value in possibly improving cell kill in some hypoxic tumours.

He considered giving tumour bearing mice 7% O_2 to breath and Hal wrote to him in Sept 1954: "The more I think about your experiment of pre-treatment with partial hypoxia to reduce the thickness of the viable 'shell' the more I like it." This heart warming enthusiasm was so typical of him. HPO was tried clinically in various radiotherapy centres and the results of a large MRC trial were published in 1978. A large improvement in local control (26%) was found and a statistically significant improvement (12%) in five-year survival of cancer of the uterine cervix was demonstrated. In other tumour sites no improvement was found. Scott had to resign as director in 1969 for health reasons.

Jack Fowler

Jack Fowler was to become the next Director. After a short period at King's, he studied neutrons at Hammersmith (becoming Professor of Medical Physics there). While working with David Bewley they "were able to compare 5 fractions per week with 5 daily fractions over 4 weeks on pig skin". These experiments were also to compare the relative biological effectiveness (RBE) of neutrons with X-rays. They found that RBE was highly dependent on fraction size (for X-rays , not for neutrons).

IMAGE: GETTY

Fowler moved to The Gray in 1969, becoming Director after Scott. One of the main concerns at that time was: how could different fractionation schedules be compared, leading to the notion of "Isoeffectiveness".

A vital understanding

By the 1980s, in Fowler's own words: "I had demonstrated (together with) Bruce Douglas that the linear quadratic was relevant to radiotherapy fraction size." Eddie Barendsen had rationalised the meaning of α/β, but it was Fowler who formalised the linear quadratic theory of cell survival and showed how some simple maths could be used by clinicians to change fractionation for the required outcome. His 1984 paper showed in simple terms the impact of "hypo" vs "hyper" fractionation.

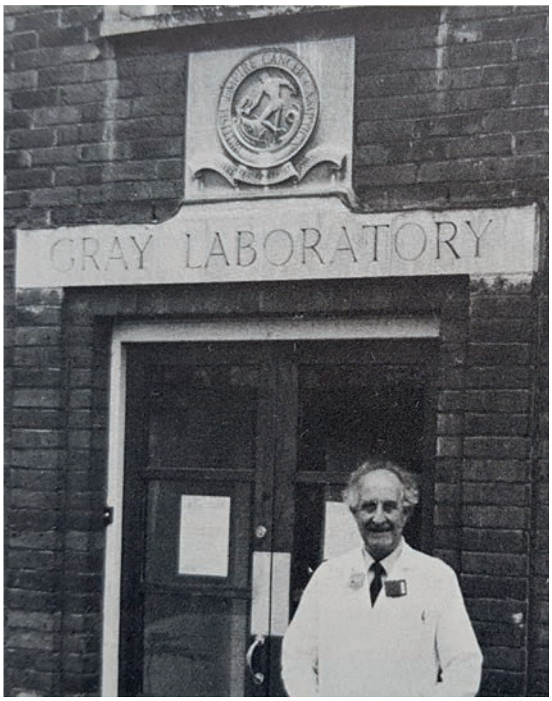
In 1982, in a Gray Lab annual report, Fowler described the sections of The Gray Lab at the time (see box, opposite). In this report Fowler concluded: "It is an exciting time now. I wonder what people will say about us in another 25 years? I shall be surprised if they then paint a picture of rustic simplicity and tranquillity. We are working long hours on ways of killing tumour cells more effectively, without causing more damage to normal tissues."

The next stage

Fowler had appointed Julie Denecamp as Head of Radiobiology applied to Radiotherapy in 1971, to investigate the effect of fraction size with an emphasis on repair mechanisms, and to explore the dissociation of acute and late effects, particularly when considering new treatment modalities. Ten years later one of her major areas of work was to begin translational research with the Oncologists within Mount Vernon Hospital (MVH). A clinical team at MVH, led by Professor Stan Dische, together with Michele Saunders, developed, in collaboration with The Gray, CHART [Continuous Hyper-fractionated Accelerated RadioTherapy: 36Gy, 3 fractions(of 1.5Gy per fraction) per day-6hour gap] as a new method of treating non-small cell cancers of the lung and head and neck.

On Fowler's retirement in 1988 Denecamp became the director of The Gray. In the 1993 Gray Lab report she wrote of her aspirations,

"IT IS AN EXCITING TIME NOW. I WONDER WHAT PEOPLE WILL SAY ABOUT US IN ANOTHER 25 YEARS?



❹ Jack Fowler in front of The Gray Laboratory entrance.
❺ Front of The Gray Laboratory (1982).

in particular a closer partnership with MVH: "Its unique position among non-teaching hospitals was highlighted when it received 65% of the whole national budget... designed to provide government support for non-teaching environments." The MVH research and development board was headed up by Dische.

Denecamp had expanded the space within the laboratory to 230 rooms. She also refurbished the chapel (previously used by patients when MVH was a tuberculosis hospital, and patients weren't allowed into the town) into a conference centre with seating for 200 delegates and an amazing sound system developed by Boris Vojnovic. This wonderfully renovated building became known as: The Fowler-Scott Library. This facility was immediately used during Fowler's retirement year.

Several meetings were organised with participants from all over the world, including: a symposium with 132 attendees; a conference entitled "The scientific basis of modern radiotherapy" with 145 delegates; and a course for radiotherapists – "Radiobiological Basis of Modern Radiotherapy".

Around this time were the first signs of potential funding problems for The Gray Lab. Strategic attempts by head office to reduce investment in radiation research led to

Denecamp leaving in 1994 to continue her work full time in Umea. While The Gray Lab continued in slimmed down form, as a trust.

Major new plan

Professor Ged Adams retired as Director of the MRC Radiobiology Research Unit to become the first Chairman of the newly established The Gray Laboratory Cancer Research Trust in 1995, at which time about 80 staff were employed by the trust (alongside about 40 visiting research staff and PhD students). His major new plan for the lab was a new building to house a 4.7T MR facility for small animal *in-vivo* imaging and functional magnetic resonance imaging (fMRI). A small positron emission tomography (PET) scanner was also planned together with a joint plan with MVH and Paul Strickland Scanner Centre to operate a cyclotron for the production of standard PET isotopes and research into new isotopes to aid imaging of special cancers. The upper floor was to house a new molecular medicine group, which was to be concerned particularly with programmes in hypoxia-based gene therapy and also joint laboratory facilities with the Department of Pathology at MVH.

In January 1998, Dr Soren Bentzen from Denmark was appointed to divide his time between the Directorate of Research and Development at MVH as an advisor in statistics and The Gray Lab as Head of Biostatistics in Oncology Group.

The beginning of the end

Very sadly, Adams died in June 1998 before completion of this project and the Ged Adams Building was opened by his widow in December 1998. The lab continued to thrive under the Chairmanship of Dische , but with the extra burden on the heads of section and lab staff generally because of the need to apply for grants to continue their work (In 1999 there were 41 applications under consideration: ranging from £10k to more than £1m). In 2001 The Gray Lab was renamed The Gray Cancer Institute.

The final years

In the 2002 research report, Dische wrote: "Much time has been devoted to the preparation of detailed proposals to Cancer Research UK, and these were finally completed and presented at the end of the year. We look forward in 2003 to a successful negotiation with Cancer Research UK (CRUK) and University College London."

Dische resigned his chairmanship at the end of 2003 and Professor David Harnden took on this role for a brief period . A special symposium (in the Fowler-Scott Library) to honour Sir Oliver Scott's 80th birthday was held in April 2003 (the year of 50th anniversary of the famous Gray, Conger, Ebert, Hornsey and Scott paper defining the "Concentration of oxygen dissolved in tissues at the time of irradiation as a factor in radiotherapy". The theme of the symposium was "Oxygen". Speakers included: Rod Withers, Jack Boag and Jack Fowler.

An internal review found that, to secure the Institute's future, it should move to an environment with a supportive research base. In 2004 Gillies McKenna was appointed Honorary Director and in 2008 the Institute relocated to Oxford to be within the CRUK/MRC Oxford Institute for Radiation Oncology where McKenna is Director.

LAB SECTIONS (1982)

a) Tumour radiobiology *in vivo* and *in vitro* (N McNally)
b) Radiobiology applied to radiotherapy: tumour and normal tissue radiobiology and cellular kinetics *in vivo* (J Denecamp)
c) Molecular radiobiology: radiation chemistry, with pharmacology and cells in vitro for the development of radiosensitizing drugs which were derived from fundamental work (P Wardman)
d) Biochemistry and microbiology (D Dewey)
e) Biophysics and Engineering : development of the submicrosecond timescale methods, design of experiments, responsibility for the radiation sources and mechanical and electronic workshop (B Michael)

Administration: (Wing Commander Hunter; Mrs Collins and J Fowler).

TECHNOLOGY SUBSTANTIATED

Most people speak about technology in terms of equipment, machines, tools and industries. This article explores the traditional meaning of technology – knowledge or study of an art or craft.

Healthcare is not a solved problem and all that needs to be known about diagnosing and treating certain diseases is still not fully known. Studying the practical use of medical equipment, in order to continually improve diagnosis and treatment of diseases, is the way forward. Diseases can be plotted on a chart showing what is understood of the mechanisms causing a disease and the extent of the efficacy of its treatment, see figure 1.

How well these diseases can be diagnosed is mapped along the horizontal axis. Diseases that can only be diagnosed through interactive testing of intuitive hypotheses, are shown to the left. Diseases where the cause is well understood are shown to the right. The current efficacy of treatment is plotted on the vertical axis. Diseases plotted at the bottom can only be treated experimentally and sometimes there are no known treatments. Diseases plotted towards the top have curative treatments. Figure 1 is illustrative, rather than exact, and offers only a snapshot in time of this sampling of diseases.

Intuitive medicine is patient care for diseases that can only be diagnosed from their symptoms and have uncertain treatment. Precision medicine is care for diseases that can be precisely diagnosed, where causes are well understood, and where treatment is rule-based and predictably effective. Empirical medicine is somewhere in between and where outcomes can be predicted in probabilistic terms, e.g. the vaccine will be effective in 90% of people.

Scientific progression takes us along the continuum from intuitive to empirical and then to precision medicine. In order to achieve this degree of precision, technology must progress interactively on three fronts:

- understanding of what causes a disease
- the ability to detect those causal factors
- the ability to treat those root causes effectively.

Science, craft and technology as evolving bodies of knowledge

Science aims to provide understanding of the universe, including all objects, situations and circumstances connected with something. These objects can either be natural or artefacts, i.e. made by humans. Craft knowledge and skills are used in both the

IMAGES: ISTOCK

production of decorative and utilitarian artefacts. Technology predominantly addresses utilitarian artefacts. Medical technology therefore predominantly addresses the use of medical equipment.

Technology is a process of enquiry and action

Utilitarian artefacts are produced by a technological method that informs and is informed by technological knowledge. The technological method is therefore concerned with the understanding, development, implementation and use of the utilitarian artefact, i.e. of medical equipment. The technological method is aimed at utility. It focuses on how an item is used, taking into account people, processes, purpose and place. This holistic approach distinguishes the technological method from traditional engineering or craft, both of which emphasise the "hardware" elements in a solution. The technological method is concerned with analysis and design. It is a way of observing and analysing the behaviour in the utilisation of an item and a way of designing an improved use, an improved item or both.

> **"SCIENCE AIMS TO PROVIDE UNDERSTANDING OF THE UNIVERSE**

Technology management

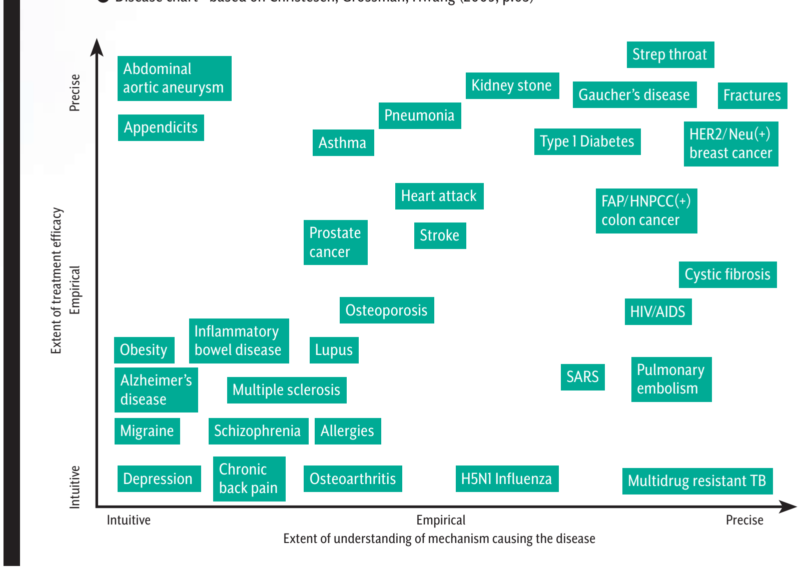
Technology management is concerned with improving the existing and long-term effectiveness of an organisation through the application of concepts, methods and techniques to the tasks of operating, improving and integrating an organisation's processes. Managing technology in healthcare, therefore, focuses attention on the processes of patient care, routines, practices and techniques. There are aspects of these processes that utilise the science that is embedded in the design of medical equipment and these processes can therefore be improved by designing an improved use of medical equipment or improving the design of the medical equipment itself.

Clinical technologists

The NHS careers web site describes a Clinical Technologist as someone who is responsible for maintaining, monitoring and operating complex, specialised equipment used in the diagnosis and treatment of patients. Their knowledge and skills in these areas can complement that of clinicians when progressing technology.

While there is a lot of support for information technology developments in the NHS, see the NHS Long Term Plan, information from studying the practical use of diagnostic and treatment equipment can inform the continual improvement of such equipment and therefore the processes that use them. Clinical Technologists can be

❶ Disease chart - based on Christesen, Grossman, Hwang (2009, p.63)



proactive in this matter, partaking in audits and clinical service evaluations where those services are highly dependent on medical equipment. Clinical Technologists can form a bridge with manufacturers, regulators and health technology assessment centres. The information crossing this bridge needs to be developed and supply chain management adopted. The use of Lean and Six Sigma approaches to improving clinical services would be a good source of this information.

Collaboration with clinicians

Research shows there is much to be gained from clinicians working with engineering teams on technology. It is essential for a close interdisciplinary collaboration between clinicians, as users of medical devices, and engineering teams who understand the design of medical devices, for technology to be successful. Knowledge, skills and techniques need to be shared, especially when improvements need a technological breakthrough.

Overcoming the barriers

Engineering teams have knowledge on medical devices that clinicians would like to use. Clinicians know that they cannot progress technology without collaborating with engineering teams. Engineering teams need to understand medical science. Clinicians need to understand engineering practices. This language barrier can be overcome by continually working at it. Collaboration can also be hindered by time and patterns of effort, especially if only a little time is set aside for the activity. Clinicians and engineering teams have many other pressures on their time and need to set aside enough time to become familiar with each others' fields.

Leadership and good communication between those involved is important. The leader of an improvement process will tend to be a clinician. Team members need to trust each other. Tatsuro Yoda found that it can be difficult for clinicians and engineers to maintain an equal partnership and clinicians tend to dominate a multidisciplinary improvement team. Yoda explains that medical doctors possess something of "a monopoly over the exercise of their work" and "special privilege of freedom from the control of outsiders" because of their high skill, knowledge, and society's trust in them. As a result, other occupations tend to be subordinate to medical doctors in authority and responsibility. It is necessary for medical doctors to understand that he or she should contribute as a team member according to their expertise.

There is a general difficulty in conducting interdisciplinary research, which includes different methods of development, standards of evidence and external recognition. Clinical study is a system of knowledge that intends to cure patients, while engineering is a system of knowledge for designing utilitarian artefacts. Although there are overlaps of those disciplines, there still remain difficulties. As part of a privileged profession, clinicians are required to continually diminish the need for their services through medical science. Doing otherwise would prolong suffering, break the Hippocratic Oath, and disrespect the privilege accorded to them by generating the need for their own services. In conflict to this, engineers are creative people who can receive recognition for having an impact on patient care and want the outputs from their efforts used widely and for some time. For the engineering teams to have an equal say in the decisions around improving clinical services they will need to align with a clinician's objective of diminishing the need for their own services, which may be seen as counter-intuitive.

Learning organisations

Setting up the delivery of services in a way that systematically provides the information on which the service can be evaluated and improved, should become the norm. Clinical Technologists have a responsibility here to influence improvements in the utilisation and advancement of medical equipment.

" GOOD COMMUNICATION BETWEEN THOSE INVOLVED IS IMPORTANT

NAMING A DISEASE

The naming of a disease does not represent fundamental understanding of a phenomenon in nature. This distinguishes medical science from the pure sciences, e.g. physics, where naming a theory does. Instead, in medical science, a disease name categorises the experience of seeking the understanding on how to diagnose and treat a disease. As the experience grows and is nuanced, the name of a disease splits into more refined terms and therefore the precision in representing this experience increases, e.g. diabetes became diabetes type 1 and diabetes type 2. Diagnosis and treatment improves as a consequence of this increase in precision.

Ste Lake *is a Consultant Clinical Scientist, in Clinical Engineering, Liverpool University Hospitals NHS Foundation Trust. References have been supplied and can be requested from rob.dabrowski@redactive.co.uk*

COACHING

A tonic for your thoughts pt. 1

Andy Nevill presents the case for coaching and shares some personal insights in the first of a three-part series.

This mini-series, which is presented over three parts, aims to provide an introduction to coaching and how it might be used to good effect in the workplace. I am writing this because I believe that my own learning, discoveries and experiences relating to workplace coaching have had a positive impact on the way in which I tackle my own work, and I wanted to share this. In one sense I am writing this article for my younger, less experienced self. I don't hold onto regrets, but I feel it would have been useful for me to have come across coaching earlier in my career, particularly around the point at which my work started to shift from technologies to people. Technologies routinely have manuals – I have yet to discover a manual for people!

For this first part I offer a definition for both coaching and mentoring, and compare and contrast these two learning interventions. I then take a brief look at the evidence base and explore how the way we think affects our feelings and behaviours.

In part two, I will describe the coaching process and identify competencies for effective coaching. I will then present a model for a coaching toolbox and describe the first section of this toolbox: process tools for the coach.

In part three, I will complete my description of the toolbox, which contains useful resources for the coach to draw upon to support their client. There are clearly numerous opportunities for healthcare scientists and I offer some practical suggestions and five recommendations. Finally, I will round off with a synopsis of my own journey, which I link to my recommendations to provide a personal reflection.

Some definitions

"I cannot teach anybody anything. I can only make them think." Socrates, Greek philosopher.

Coaching and mentoring are frequently discussed together and the common purpose is the "learning and development of an individual".

There are numerous published offerings of a definition for coaching. Parsloe (1999) describes the purpose of coaching and mentoring as "to help and support people to manage their own learning in order to maximise their potential, develop their skills, improve their performance and become the person they want to be". The work of Cox, *et al.* (2014) is described by Megginson as "the most comprehensive handbook that I know" and suggests that creating a unique identity of coaching remains an unsolved problem. They go on to suggest that authors should then attempt to define coaching themselves so that readers are able to see their positions in relation to what coaching is.

Cox, *et al.* (2014) offer the following definition for coaching: "Coaching is a human developmental process that involves structured, focused interaction and the use of appropriate strategies, tools and techniques to promote desirable and sustainable change for the benefit of the coachee and potentially for other

IMAGES: GETTY

stakeholders." This is the preferred working definition for coaching for the purposes of this article.

Clutterbuck (2014) has been instrumental in the development of mentoring and describes how this "journey" has been influenced by organisational and national culture and also the emergence and development of other forms of 1-2-1 developmental help such as coaching. He suggests there are broadly two perspectives for the definition of mentoring.

Firstly, with origins primarily in the US: an emphasis on sponsorship and hands-on help from the mentor. Six definitions of this type are cited. Words within these definitions include "oversee", "responsible for" and "protégé" which reinforce the hands-on nature of the relationship and a sense of senior and subordinate. A protégé is someone who is protected.

Secondly, with origins primarily in Europe, an emphasis on helping people to do things themselves. Twelve definitions of this type are cited. Words within these definitions include "co-learning", "assisting", "deeper self-awareness" and "learner" and there is less emphasis on any difference in power.

Clutterbuck suggests that the following definition is most commonly used for developmental mentoring: "Off-line help from one person to another in making significant transitions in knowledge, work or thinking" (Megginson & Clutterbuck, 1995). This is the preferred working definition for mentoring for the purposes of this article.

Coaching is widely used in different situations, for example, sports coaching, business coaching, life coaching and coaching to support healthcare interventions. Workplace coaching is the focus of this article, which is an organisational intervention that is designed to support and enhance individual and organisational performance (Passmore, et al., 2019). For reasons of brevity this article refers to coachees and mentees as "clients".

Alongside coaching and mentoring, there are other learning interventions, including training, consultancy and counselling. Figure 1 shows an interpretation of coaching sitting between training and mentoring.

With reference to the preferred working definitions provided above there are many similarities between coaching and mentoring and a better understanding of both can be achieved by looking at the differences (see box).

> "COACHING IS FUNDAMENTALLY A STRUCTURED OPPORTUNITY FOR THINKING

The evidence base

Hamlin, *et al.* suggest that coaching is at the heart of managerial effectiveness (Ellinger, *et al.*, 2014). There is a developing evidence base for coaching and *Cox, et al.* (2014) provide an overview of outcomes research and evidence for efficacy. The evidence base is broadly divided into studies relating to context, benefits and outcomes of coaching, benefits and outcomes for the client, attributes of the coach and coaching practice and models. Passmore, *et al.* (2019) describe five phases of development of coaching research, which is not dissimilar to many areas of human resources practice and that can be traced back to 1995. It is suggested that following the initial stages of "exploration" and "theory building" we are now seeing the publication of randomised controlled trials (third stage) and are moving into the forth stage in which meta-studies and reviews of the literature seek to confirm the validity of the approach. A fifth stage is predicted to emerge that will seek to explore exceptions to and variations from the established theories.

Some studies are seeking to understand the impact of coaching on "hard" measures of organisational performance although there is debate about the value and utility of studies that investigate return on investment (ROI). Grant (2012) argues that "overly focusing on the potential monetary gains to be made from coaching gives an extremely limited view of the potential benefits", and advocates using a well-being and workplace engagement framework (Grant & Spence, 2010) to

COACHING AND MENTORING

- A coaching programme could take different forms and will be more formally contracted and structured compared with a mentoring relationship with is more informal .
- A coaching programme is typically time-limited and addresses a current short-term need whilst a mentoring relationship will be longer term.
- A coach will be in control of the coaching process whilst a mentor will relinquish more control to the client.
- A coach will focus on the present whilst a mentor will spend more time focusing on the future.
- Coaching will be task-focused whilst mentoring is concerned with implications beyond the task and perhaps wider professional and career development.
- A mentor will usually be a subject expert or a peer whilst a coach's subject expertise does not need to match to that of the client.
- A coach will focus on questioning and self-discovery whilst a mentor will offer more advice and might be more actively involved in agreed action.
- A coach will be an advocate whilst a mentor will be more of a teacher and a guide.

evaluate coaching success given that "organisations function better with mentally healthy employees who are engaged in their work activities".

With the current evidence base it is reasonable to conclude that coaching can be an effective learning intervention for individuals and for an organisation as part of an organisational development strategy as long as best practices are adopted.

The power of a thought

"If you don't like something, change it. If you can't change it… change the way you think about it." Mary Engelbreit, artist.

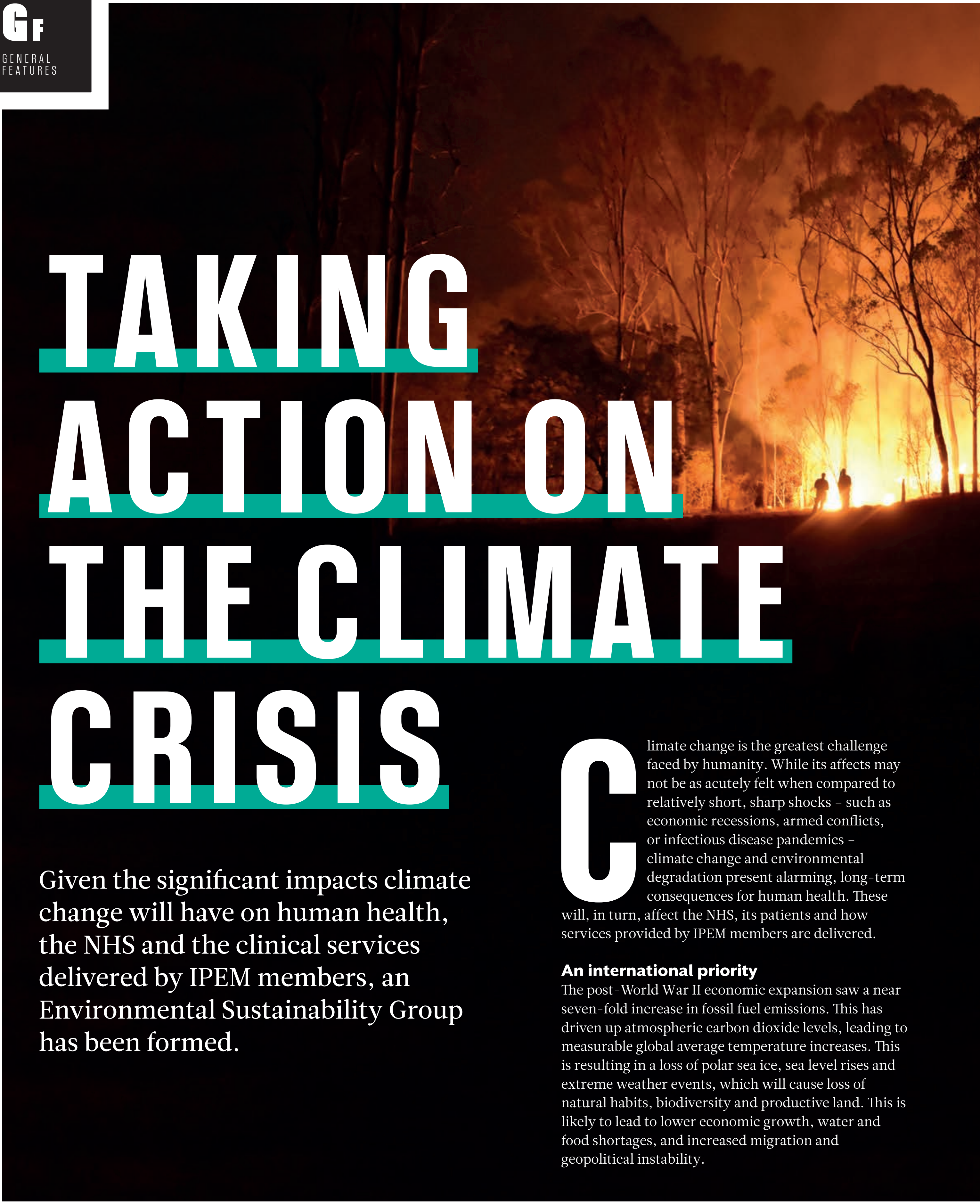
There is a relationship between our thoughts, feelings and behaviours and this is often referred to as the cognitive triangle as shown in figure 2.

Bandura (1969) writes that "humans are, first and foremost, thinking beings, capable of organizing their behaviour and modifying it according to circumstances". This suggestion that people think before they do then sets the stage for the development of cognitive behavioural therapy. Cognitive behavioural "coaching" is just one of numerous theory-based approaches to coaching and underpinning all approaches are the theories of adult learning. Setting theories aside, coaching is fundamentally a structured opportunity for thinking and any resulting changes in behaviour would suggest that learning has taken place.

Figure 1 Interpretation of coaching, sitting between training and mentoring

Figure 2 The cognitive triangle

***Andy Nevill** is a Consultant Clinical Scientist and Interim Head of Medical Physics at Royal Devon & Exeter NHS Foundation Trust. He thanks Enno Siziba, Dynamics Corporate Consulting (Pty) Ltd, for the reproduction of Figure 1. For references to accompany this article, email rob.dabrowski@redactive.co.uk*



TAKING ACTION ON THE CLIMATE CRISIS

Given the significant impacts climate change will have on human health, the NHS and the clinical services delivered by IPEM members, an Environmental Sustainability Group has been formed.

Climate change is the greatest challenge faced by humanity. While its affects may not be as acutely felt when compared to relatively short, sharp shocks – such as economic recessions, armed conflicts, or infectious disease pandemics – climate change and environmental degradation present alarming, long-term consequences for human health. These will, in turn, affect the NHS, its patients and how services provided by IPEM members are delivered.

An international priority

The post-World War II economic expansion saw a near seven-fold increase in fossil fuel emissions. This has driven up atmospheric carbon dioxide levels, leading to measurable global average temperature increases. This is resulting in a loss of polar sea ice, sea level rises and extreme weather events, which will cause loss of natural habits, biodiversity and productive land. This is likely to lead to lower economic growth, water and food shortages, and increased migration and geopolitical instability.

The level of mitigation required to keep the global temperature increase at or below 1.5ºC (deemed a safe "upper limit") becomes increasingly severe with each year mitigating measures are not taken (see figure 1). The seriousness and immediacy of this situation is becoming an international political priority.

Climate change is also having a detrimental effect on human health. Heat waves and increasing global temperatures are resulting in early deaths due to dehydration and cardiovascular, respiratory and cerebrovascular diseases. More frequent extreme weather events reduce availability of clean food and water, damage infrastructure and strain emergency and healthcare services.

As animals are displaced from their natural habitats, or habitats are invaded by human activity, diseases carried by insects or other animals will spread. Lack of access to clean water and the agricultural processes that will be required to produce food from progressively less fertile land will increase incidence of waterborne diseases and chemical contamination of food and land. Additionally, increased fine particulate emissions due to human activities have driven a rise in respiratory and cardiovascular diseases and cancer risk.

Ambitious plans

However, the provision of healthcare itself is a carbon intensive endeavour, with the NHS accounting for an estimated 5.4% of the UK's carbon footprint. The NHS has recently announced ambitious plans to improve its environmental sustainability and reach net zero carbon emissions by 2040. It has also identified that all aspects of the organisation – from the supply chain, transport, catering, estates and facilities to front-line service delivery – must become more sustainable.

IPEM, an institute made up of scientists, engineers and technologists, who are problem solvers by trade and are both scientifically literate and experienced in the complex requirements of healthcare services, has a significant role to play in tackling the climate emergency in healthcare.

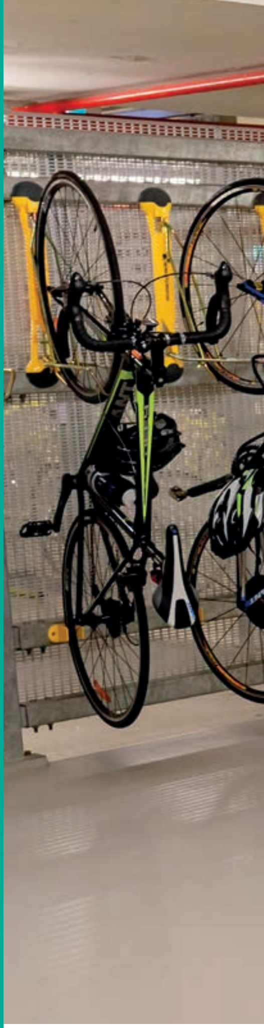
Member survey

An IPEM Environmental Sustainability Group (ESG) has therefore been formed, with four central aims (see box). One of the group's first activities was to survey IPEM members on the issue of climate change to gauge members' interest, understanding and current activities in this area. In total, 189 responses were received, with 33 employers named by the respondents. In total, 92% of the respondents worked for an NHS trust. When asked: "Are you interested in environmental sustainability?" 98% of respondents said yes, with many of the respondents indicating that they already engaged with environmental and sustainable activities in their personal lives and wished to move this into their work lives too. While 81% of respondents said yes to "do you think that health and sustainability are linked?" The question "do you feel

IPEM ESG AIMS

- Promote environmental sustainability to and within medical physics and engineering
- Engage and support members on environmental sustainability
- Advise IPEM Trustees on environmental sustainability
- Engage with others, including manufacturers and funding bodies, nationally and internationally, on improving environmental sustainability.

"CLIMATE CHANGE IS HAVING A DETRIMENTAL EFFECT ON HUMAN HEALTH



your organisation prioritises the environment/sustainability at work?" resulted in 22% of respondents saying they strongly agreed or agreed, with 30% responding "neither," 41% saying "disagree" and 7% responding "strongly disagree." Respondents were then asked "what does your organisation do to promote sustainability?" Responses are shown in figure 2. Further free text responses included paperless working/the use of recycled paper (n=2), fitting electric car charging points (n=1), automatic lighting (n=1), enabling working from home (n=2), the installation of solar panels (n=1), the use of an onsite incinerator to provide heating (n=1) and the provision of a free electric bus service between sites (n=1). Two respondents said that their organisation had a designated sustainability group/officer, while three stated that their organisations had formally declared a climate emergency. Seven respondents reported that "things have gone backwards during COVID," while six detailed a "lack of recycling bins."

> **"CLIMATE CHANGE IS THE GREATEST CHALLENGE**

Only 18% responded yes to "are you aware of the need for your trust to say how it is going to go carbon zero by 2050 under the NHS sustainable development plans?" with the remaining 82% saying no. This potentially shows a lack of action and/or engagement with staff on these issues at NHS trusts; both are worrying considering the need for unprecedented change.

Figure 1 The carbon budget to keep the global temperature rise below 1.5°C, and the range of mitigation levels required.

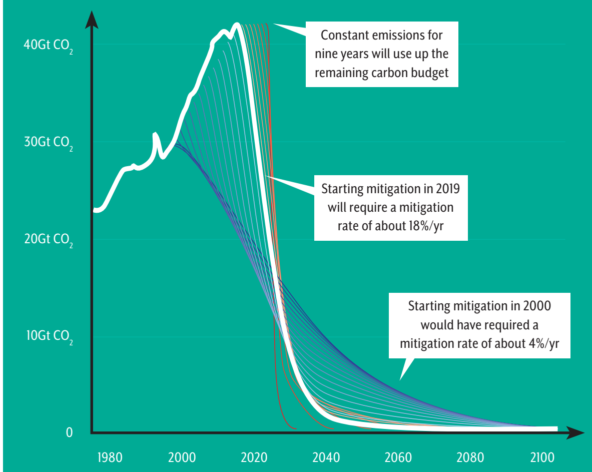
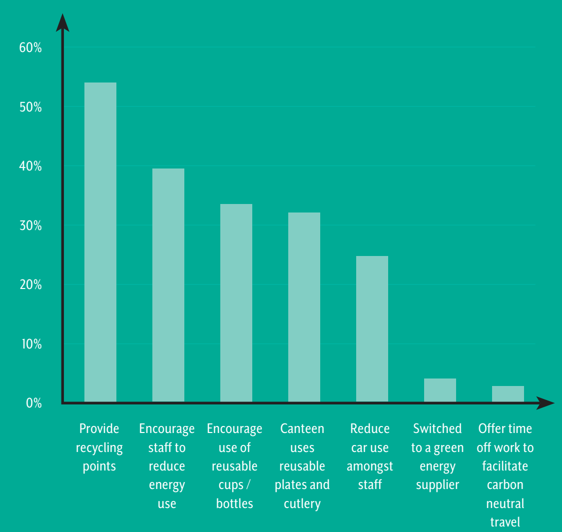


Figure 2 The environmental and sustainability activities survey respondents reported their organisations carrying out.



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Demonstrate leadership

The top five responses to the free answer question "what change would you most like to see in your workplace in the next five years?" were:

- Improved recycling facilities (n=32)
- Continued remote working/meetings (n=19)
- Improved efficiency of buildings (n=16)
- Improved cycling facilities (n=14)
- Incentives for using public transport (n=14).

Notably, these could be seen as generic improvements, rather than healthcare or medical physics and clinical engineering specific issues (e.g. minimising diagnostic or therapeutic equipment energy consumption, or the optimisation of medical procedures to reduce demand on resources).

For the final question "do you believe that it is important that IPEM prioritise sustainability?" 86% of respondents said yes, 10% didn't know and 4% said no.

Free text remarks highlighted that IPEM was well placed to demonstrate leadership on the issue, and that providing scientific leadership in healthcare on the climate emergency was aligned with IPEM's charitable aim to "advance physics and engineering applied to medicine and biology for the public good." Indeed, members' scientific and technical roles in healthcare can be seen to give a pragmatic view, balancing the trade-offs of sustainability, financial constraints and the clinical requirements of products and services for patient care (which, as healthcare professionals, we must put first). Furthermore, scientific leadership on workplace environmental sustainability initiatives may serve to draw

attention to potential technical improvements in the clinical areas served by IPEM members, where focus may otherwise be on more generalised measures.

A total of 1% of respondents said yes to the question "is IPEM is doing enough to reduce its carbon footprint?", 17% said no, and 82% said they did not know. This indicates that more needs to be done and that awareness of what IPEM is already doing needs to be raised.

Actions and suggestions

Some of the actions that IPEM has taken to improve its environmental sustainability include:

- No longer providing paper copies of conference materials, conference bags or other "freebies"
- Ensuring event venues have good public transport links
- Single-use plastic is not used at venues
- *Scope* is no longer mailed in any packaging
- The provision of some online meetings (note: this was being done prior to COVID-19 pandemic).

Further suggestions of what IPEM could do included:

- Continued provision of online/hybrid conferences and meetings after the COVID-19 pandemic (which can also improve accessibility and participation, where travelling to physical meetings is challenging for members due to a variety of circumstances and commitments)
- Providing electronic copies of *Scope*
- Offering grants and prizes for environmental projects in healthcare or the use of low carbon travel to overseas events
- Helping members improve sustainability at their employing organisations.

Appetite and opportunity

The responses to the survey demonstrated an appetite and opportunity for IPEM and its members to take the lead in improving environmental sustainability in our sector. To further this, an environmental sustainability session was included in the 2020 MPEC programme. This included talks from representatives of Green Labs (LEAF) and the Centre of Sustainable Healthcare, which respectively seek to make scientific laboratories more environmentally friendly and facilitate sustainable quality improvements in healthcare.

By growing relationships with such organisations, acting as a hub for IPEM members interested in driving forward sustainability in their workplaces and providing a framework for other initiatives (such as technical reports, assisting with MSc/elective projects, or training and educational resources on environmental best practice), the IPEM ESG will help to make medical physics and clinical engineering services less carbon intensive. Further suggestions of what the ESG can do to support members are welcome.

For more information, or if you would like to participate, please contact **Robert.Chuter@nhs.net**, visit **bit.ly/IPEM_ESG** or follow **@IPEMEnvironment**.

Dr Nathan Dickinson *is Principal Clinical Scientist at Medical Physics and Clinical Engineering at the Nottingham University Hospitals.* ***Dr Robert Chuter*** *is Principal Clinical Scientist in Radiotherapy at The Christie NHS Foundation Trust and Honorary Lecturer at The University of Manchester.*

Radiotherapy Physics Dosimetrist **Dan Murray** and colleagues investigate if the two state-of-the-art radiotherapy technologies could provide a more efficient and effective means of delivering radiotherapy for left-sided breast cancer patients.

The future of breast cancer radiotherapy

With around 63% of all breast cancer patients receiving a form of radiotherapy at some point during their treatment, it has never been more essential to continue research into the newest and most innovative methods available.

My recent study has aimed to evaluate if the two most recent advancements in radiotherapy technology (see box, right) could be introduced for breast cancer effectively, and to generate discussion into the current and future positions of breast radiotherapy in the UK.

Former and current methods

Radiotherapy for breast cancer or, more accurately, whole-breast irradiation, represents a large patient cohort, with an estimated 500 patients annually in Swansea alone. Consequently, the chosen radiotherapy technique must be able to maintain plan quality across this large group, whilst retaining the ability to individualise the treatment for each patient.

A clinically effective treatment technique for left-sided breast cancer is described in Figure 1:

Most departments within the UK opt for one of, or variations of, these two methods. Swansea Bay used a 3D_CRT approach previously (Figure 2), which involved manual optimisation of the plan. Then they

Figure 1 Technique characteristics

The optimal quantity and intensity of radiation to the whole breast, where the distribution of this radiation dose is conformal and homogeneous.

Dose to the heart and ipsilateral lung must be kept as low as reasonably possible, given the proximity to the high dose level in the left breast.

Dose to the contralateral organs at risk and normal tissue must be kept as low as reasonably possible, to reduce the risk of short, or long-term side effects.

advanced the technique by adding two inversely optimised intensity modulated radiotherapy (IMRT) fields (Figure 3), offering improvements to the conformality of the dose and lowering of OAR doses. Swansea plan all other sites with VMAT, with IMRT only being used for breast patients currently.

However, due to the static nature of these methods, VMAT, which rotates, presents new opportunities to improve dose conformity to the breast and to reduce OAR doses. However, this rotation may contribute extra dose to the contralateral breast/lung, increasing the risk of secondary malignancy induction – hence the current national consensus to remain with static methods.

This could be especially prevalent with full arc VMAT (Figure 4), given the larger arc rotation. Partial arc or "bowtie" VMAT (Figure 5) could retain the dose conformality advantages whilst reducing this risk, as these arc angles can be manually reduced to avoid dose exiting through contralateral organs. Both VMAT techniques were investigated with and without FFF, to assess the impact it may have on reducing treatment time and patient breath-hold. The dose rate was increased from the standard 600 monitor units (MU)/minute (min) to 1400MU/min (for FFF).

RADIOTHERAPY TECHNOLOGIES

Volumetric modulated arc therapy (VMAT) – The gold standard radiotherapy technique currently, utilising rotational radiotherapy beams to conform the radiation dose to complex tumour volumes.

Flattening filter-free (FFF) radiotherapy – Removal of radiation beam flattening filter can allow for much faster radiotherapy treatments.

Methodology

Six techniques were assessed in this study. Five patients were re-planned with all six techniques, where the three most optimal techniques were identified. Then another five patients were re-planned with these three optimal techniques, providing a 10-patient sample for the three methods. All patients presented standard breast anatomy and all were randomly selected for this study. A prescription of 40Gy in 15 fractions was used (study completed before new fractionation was routine – 26Gy in 5 fractions).

- 3D conformal
- Hybrid IMRT
- Full arc VMAT (f_VMAT)
- Partial 'Bowtie' arc VMAT (b_VMAT)
- Full arc VMAT + FFF (f_VMAT FFF)
- Partial 'Bowtie' arc VMAT + FFF (b_VMAT FFF).

Findings

As hypothesised by the literature and shown in my results, both full arc VMAT techniques are not a viable option, given the increases to contralateral organ dose (Figures 6 and 7) compared to the standard static approaches. Additionally, both techniques present no statistically significant improvement to dose conformity and homogeneity over partial arc VMAT and IMRT. As a result, both were removed from further investigation.

3D conformal also performed poorly, by comparison,

Figure ❷: 3D Conformal Radiotherapy (3D_CRT)

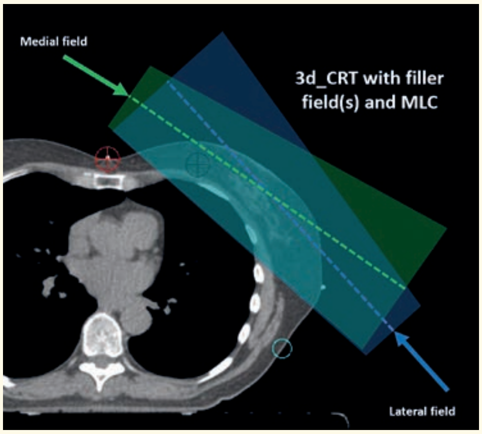
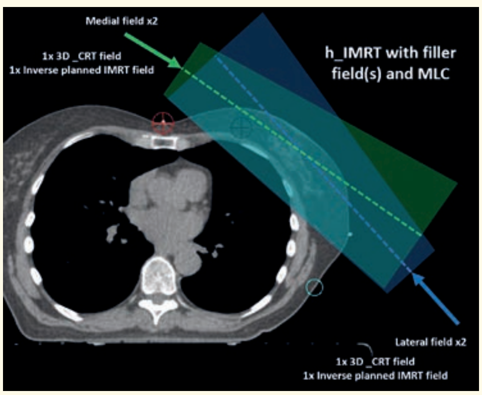


Figure ❸: Hybrid 3D/Intensity Modulated Radiotherapy (IMRT) (h_IMRT)



exhibiting sub-optimal target conformity, which subsequently was shown to increase ipsilateral lung dose to a higher level than the other five techniques. Again, this could be potentially due to the simplistic nature of this method and as a result, it was not taken forward.

The primary finding of this study was that no dosimetric difference in plan quality was observed between hybrid IMRT and both partial arc VMAT plans. The results showed no statistical significance concerning OAR or target volume doses amongst these three techniques. However, there were slight increases to the contralateral organ doses and low dose bath to normal tissues with the partial arc methods.

The second significant finding was that FFF for partial arc VMAT dramatically decreased the total beam delivery time, with a minimal loss in dose homogeneity.

In addition, no statistically significant difference in dose homogeneity was observed between both partial arc variations, indicating the change in beam profile with FFF may not worsen overall dosimetry. On the other hand, all FFF plans raised the plan Monitor Units (MU) significantly when compared with FF plans. Despite this, FFF provides scope to improve treatment capacity, given the drastically faster treatment times.

Discussion

The results highlight the feasibility of partial arc VMAT for left-sided breast radiotherapy, given the comparability with existing methods (h_IMRT). Although minimal, the impact of increasing contralateral dose exposure with partial arc VMAT must be further investigated to understand if it will cause a detrimental impact clinically. These small increases were again observed with total plan MU and exposure to normal tissues. Consequently, simultaneous integrated boosts would also become possible with partial arc. However, this leads to an increased delineation demand for clinicians. In addition, VMAT's advantages could be seen further if target volumes were delineated, rather than field-based surrogate volumes.

Although this study highlights the potential efficacy of partial arc VMAT and FFF, many variables must be considered in future research before any clinical implementation. For example, a larger patient cohort is required, as these techniques also need to account for more

Figure ❹: Full arc VMAT beam arrangement

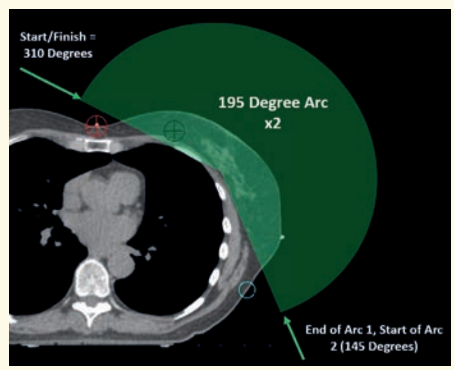
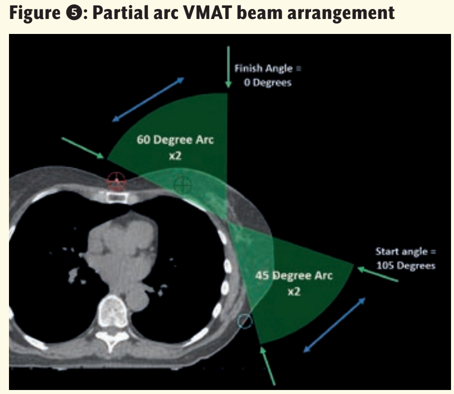


Figure ❺: Partial arc VMAT beam arrangement



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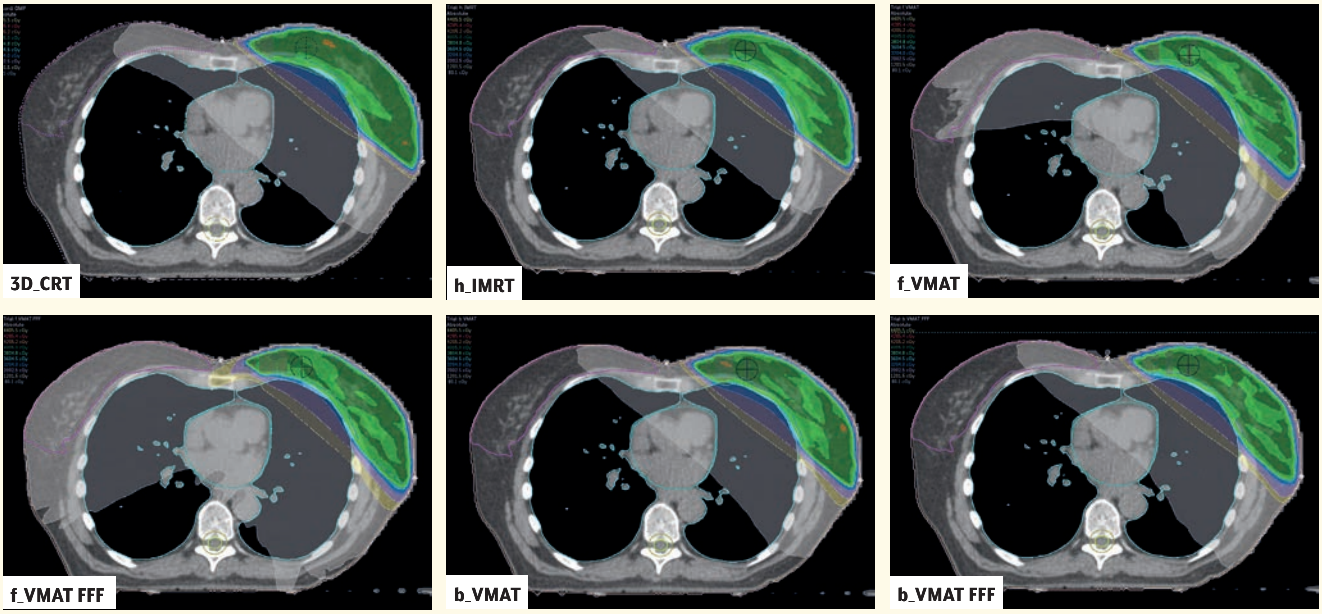
MANY VARIABLES MUST BE CONSIDERED IN FUTURE RESEARCH BEFORE ANY CLINICAL IMPLEMENTATION

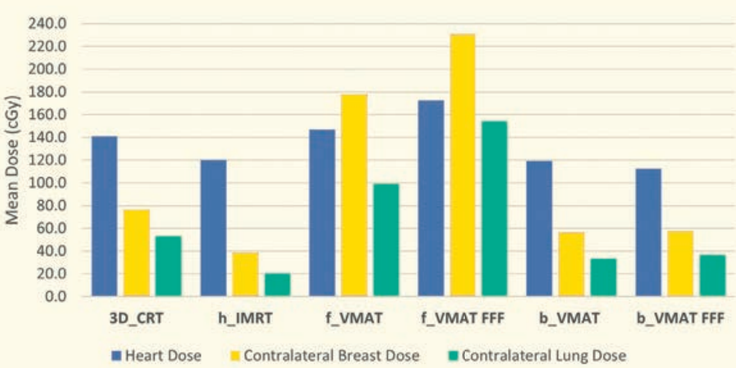
Figure ❻: Dose distributions



complex anatomy, bolus and breath hold. Further research is required into free-breathing protocols for partial arc, as breath hold was completed for these 10 patients. Additionally, the impact on the Internal Mammary Chain needs to be assessed, as it did not fall within the remit of this study.

Also, considering the updated breast prescription to 26Gy in 5 fractions, FFF could provide further reduce treatment time given the increased dose per fraction. A commissioned FFF model may slightly affect the dosimetric distribution, therefore, further analysis is required. Moreover, the increase in MU per plan with FFF is a point for discussion for clinicians and treatment planners, given the risk of secondary cancer induction with each Gray (Gy) of dose.

Figure ❼: Mean doses to organs at rick (cGy)

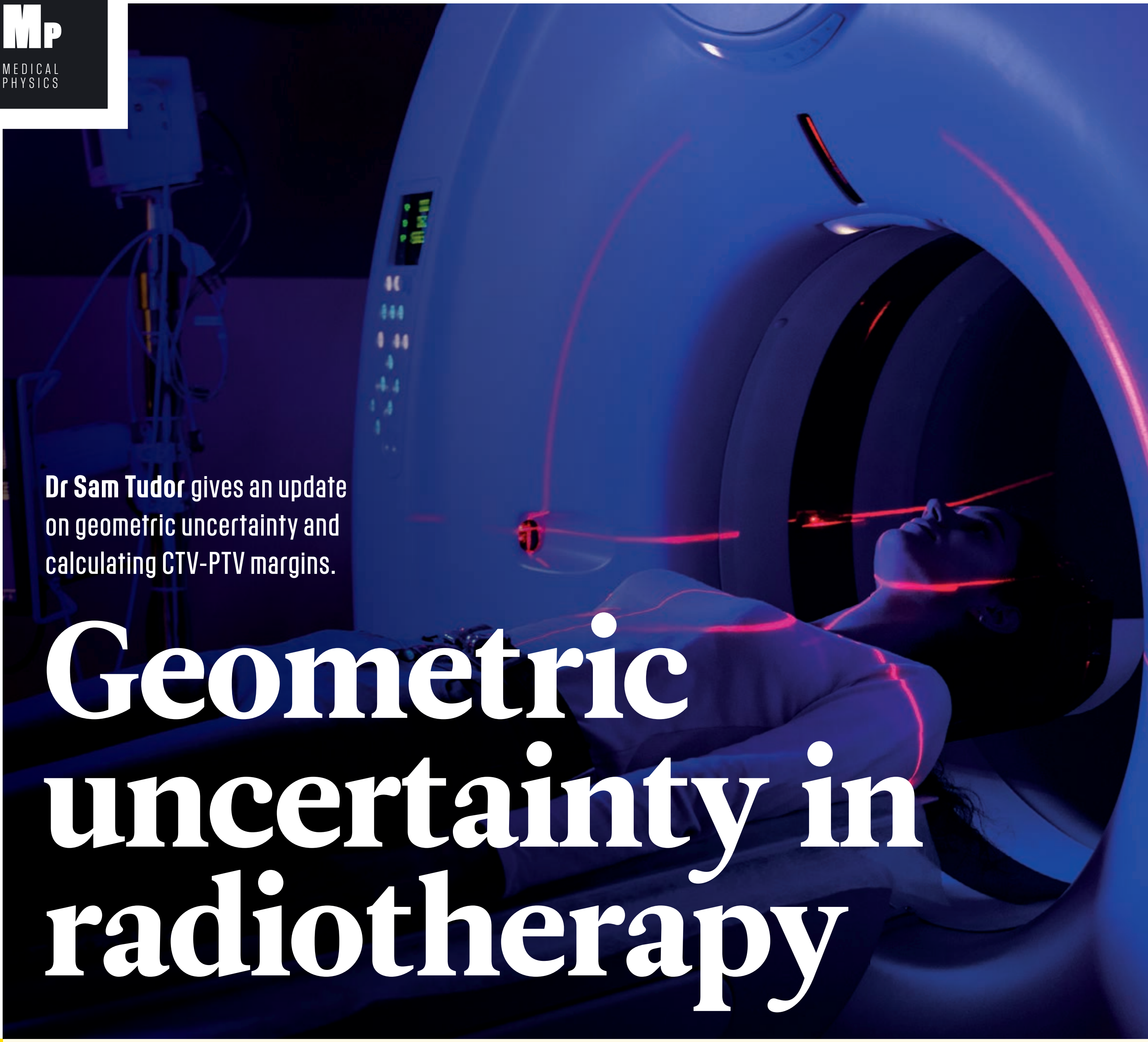


Future

This study has highlighted the potential positive impact that partial arc VMAT and FFF could have on left-sided breast radiotherapy in the future.

The increased target dose conformity and faster treatment times shown here present a noteworthy methodology for the future, especially as the prevalence of VMAT grows nationally. However, as highlighted in the discussion, partial arc VMAT should be investigated further to understand its effectiveness in a wider variety of clinical scenarios, such as its implications to practical dosimetry. Current research suggests a hybrid IMRT/VMAT approach could be a convenient stepping-stone towards sole VMAT integration, again opening the door to simultaneous integrated tumour bed boosts, integrated supraclavicular fossa treatment and improvements to breath-hold. ⭘

Dan Murray, *Radiotherapy Physics Dosimetrist, Velindre Cancer Centre, Cardiff*, **Joseph Flaherty**, *Deputy Clinical Technologist, and* **Douglas Etheridge**, *Head Clinical Technologist, both from Radiotherapy Physics, Swansea Bay University Health Board.* *The lead author would like to thank the fantastic team at Swansea for their support with this project and their guidance during his degree. He would like to particular thank Joe Flaherty and Douglas Etheridge for their valued expertise and contribution to the success of the project.*



Dr Sam Tudor gives an update on geometric uncertainty and calculating CTV-PTV margins.

Geometric uncertainty in radiotherapy

For many years, the impact of geometric uncertainty has been incorporated into radiotherapy treatment plans through the use of margins. These are described at length by ICRU Report 50, and refined by ICRU Report 62. In brief, clinical uncertainty in the degree to which subclinical spread may have occurred outside the periphery of the gross tumour volume (GTV) is accommodated in the clinical target volume (CTV). The CTV can then be grown by a margin designed to reflect all remaining causes of geometric uncertainty in order to create the planning target volume (PTV). It is the PTV that is ordinarily then used for beam-shaping, and as the basis for volumes used in inverse-planning optimisation.

The size of the CTV-PTV margin is, therefore, a crucial consideration, which will affect the balance of efficacy and toxicity of a radiotherapy treatment. Margins that are too large cause over-irradiation of neighbouring normal tissues, including organs-at-risk. Small margins threaten the coverage of the CTV, and have been associated with decreased control in published outcome data. Optimisation of the CTV-PTV margin is, therefore, clearly in the interests of the patient.

In 2003, the British Institute of Radiology (BIR) published a working party report entitled *Geometric Uncertainties in Radiotherapy*. It offered guidance on aspects of geometric uncertainty required

to implement these ideas. It featured clinical chapters relating to the most common treatment sites in radiotherapy and offered advice on localisation, imaging techniques, and generation of the GTV, CTV and the PTV. Also included were clinical and technical overviews of geometric uncertainties in radiotherapy, the latter of which categorised errors into different types. It then provided a framework for these errors to be included in CTV–PTV margin recipe.

It is, in short, a cracking read, and remains a key text for radiotherapy professionals who wish to more fully understand the process of generating a PTV from the available clinical information. However, the clinical environment has changed considerably in the last 18 years. Even ignoring the expansion in particle therapy and the development in non-margin methods of accommodating geometric uncertainties, the information contained within the 2003 report does not easily allow professionals to characterise geometric uncertainties in modern radiotherapy. In particular, the prevalence of daily on-line image-guided radiotherapy (IGRT) with online correction negates many errors described in the original report (such as bulk interfraction motion) and replaces them with different, albeit smaller, sources of geometric uncertainty (such as IGRT matching error).

Common treatment methods

The BIR Oncology and Radiotherapy Special Interest Group recognised that radiotherapy professionals and patients of today would benefit from enhanced and updated guidance related to the measurement of sources of geometric uncertainty in contemporary radiotherapy techniques. A Geometric Uncertainties Working Party was formed; the party consisted mostly of IPEM members, with multi-professional representation in the form of a clinical oncologist and therapy radiographer. Our aim was to extend the methodology of the 2003 report to the common treatment methods of today, including daily online IGRT, volumetric modulated arc radiotherapy (VMAT) and stereotactic body radiotherapy (SBRT). The focus was purely on the actions required to calculate the CTV-PTV margin – we did not reproduce the full clinical discussions of the 2003 report. Updated guidance on the clinical practice and theory of modern IGRT is available elsewhere, and will be well-covered by the upcoming update of *On Target* by the Radiotherapy Board.

We were delighted in November 2020 to publish our document, *Geometric Uncertainties in Daily Online IGRT: Refining the CTV-PTV Margin Calculation for Contemporary Photon Radiotherapy*, available free of charge on the BIR website. It first categorises the residual errors that remain after the use of daily online IGRT, including practical advice on quantification. The division of errors into systematic and random components remains a key recommendation. Sources of residual geometric uncertainty in daily online IGRT are specified as:

- Delineation and fusion errors
- Deformation error
- Rotational error
- Intra-fraction motion (both periodic and non-periodic)
- Surrogate error
- Matching error
- Technical delivery accuracy.

Respiratory intra-fraction error

A key difference to the recommendations

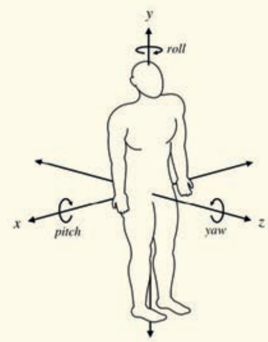
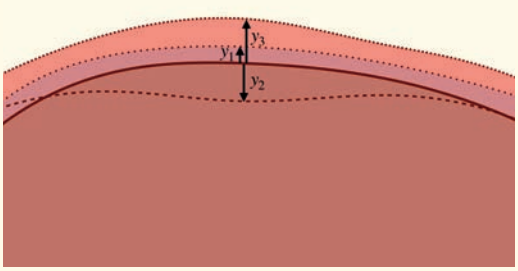


Figure 2 Contribution to CTV-PTV margins resulting from target rotation about each of the three principle axes are explored in the report.

Figure 1 Delineation error can be measured from the deviation of repeat outlines from an arbitrary reference, as shown here. However, we present a simplified estimate based on the observed range of observers' outlines.



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of the 2003 report is the treatment of respiratory intra-fraction error. The original report suggested that the respiratory amplitude should be linearly added to the PTV margin. This, like the modern use of an internal target volume (ITV) or moving GTV, aims to ensure full geometric coverage of the CTV during respiratory motion. In practice, it has now been demonstrated that dosimetric coverage of the CTV can be maintained by considering the main part of respiratory motion as a random error. This can lead to surprisingly small contributions to the final PTV margin from respiratory motion, but does require the identification of the mean tumour position during respiratory motion. All the required information for the determination of the mean position is available in a four-dimensional CT (4DCT) scan, but without specialist software, increased oncologist, technologist and physicist time may be required.

Sources of uncertainty

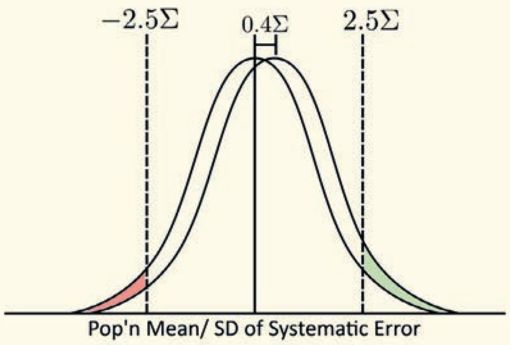
The next section of the document gives guidance on the combination of sources of uncertainty and calculation of the margin, along with discussions on statistical considerations of relevance. This includes a change in the recommendation of the determination of the effect of the penumbral region on the effect of random errors, a discussion of the effects of non-standard normalisation (such as that commonly found in SBRT techniques) on the margin formula, and a note on the effect of a limited number of fractions. We also introduce a simple method of estimating population standard deviation from the range of a small number of measurements, particularly suitable for measures of deformation or delineation in small studies within an individual centre.

The report is completed with two clinical examples. The Lung SABR example exemplifies several of the recommendations in the report, and provides interest in terms of comparison with current common practice. Key points from this example are therefore presented here as a case study. Please note that data presented here is purely to permit the example calculation to proceed. In most cases it is simulated, and it is not presented as being representative of the patient population.

Our example is unusual as we consider a volume planned and delivered such that the mid-ventilation position of the tumour is matched using 4DCT, and the intrafractional breathing motion is primarily included as a random error. The prescription is such that the isodose conforming to the PTV is 80% of the maximum dose at the centre of the target. 4DCT shows that respiratory amplitude is 15mm in superior-inferior, 5mm in anterioposterior, and 2mm in the lateral direction.

The values calculated as part of the example can be found in Table 1. Particular items of interest are discussed here.

Figure 3 Overall population mean errors small in comparison with the systematic error, Σ, can usually be ignored. Here a population mean of 0.4 Σ results in loss of geometric coverage (red) for some patients, but a gain in geometric coverage (green) for almost as many.



Delineation – The delineation standard deviation was estimated by measuring the range in a multi-observer study, and dividing by a factor dependent on the number of observers. The use of the standard value of 2.5 for the multiplier, α, is less certain for delineation error than for other sources of geometric uncertainty. Ideally, the delineation error study should be examined not only for the range to determine the standard deviation, but also to determine that a multiplier of 2.5 successfully encloses approximately 90% of the contour variation seen.

$$M = \alpha\Sigma_{total} + \beta\left[\sqrt{\sigma_{total}^2 + \sigma_p^2} - \sigma_p\right]$$

Equation 1 Margin formula recommended in the BIR update. α and β are constants depending upon the margin criterion and plan characteristics. Σ_{total} and σ_{total} are the individual systematic and random error components, respectively, added in quadrature. σp is a measure of the penumbral width.

Intrafraction respiratory motion – As 4DCT is used to position the centre of the observed daily respiration cycle with the planned mid-ventilation position, there is no contribution from inter-fraction baseline shifts. Intrafraction regular respiratory motion is modelled as a random error, as the dosimetric effect is one of blurring. Using a relationship from the report leads to calculated standard deviations of $\sigma_{respiration,\,x}$ = 0.3mm, $\sigma_{respiration,\,y}$ = 5.4mm, and $\sigma_{respiration,\,z}$ = 1.8mm. Allowance for potential intra-fractional variation is also included as both systematic and random components.

Penumbral width – The distance between the 60% and 80% isodoses was measured

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A COMBINATION OF FACTORS MAKES THE IMPACT OF RESPIRATORY MOTION SURPRISINGLY SMALL

Table 1 Example uncertainty data and margin calculation for a lung SABR case. All values in mm.

Systematic errors	**Lateral**	**Superior-inferior**	**Anterioposterior**
Delineation	2.1	2.1	2.1
Rotational	0.3	0.3	0.3
Intra-fraction	0.8	0.8	0.8
Matching	0.7	0.7	0.7
Tech accuracy	0.7	0.7	0.7
Σ_{total}	2.5	2.5	2.5
Systematic margin	6.2	6.2	6.2
Random errors			
Rotational	0.3	0.3	0.3
Intra-fraction	1.1	5.5	2.0
Matching	0.9	0.9	0.9
Tech accuracy	0.5	0.5	0.5
σ_{total}	1.5	5.6	2.3
β	0.84	0.84	0.84
σp	7.6	7.6	7.6
Random margin	0.1	1.5	0.3
Total margin, M	**6.3**	**7.7**	**6.5**

to calculate the penumbral width, σ_p. Using a relationship in the report this gives σ_p=7.6mm

Value of β – As the 80% (rather than the 95%) isodose is being conformed to the PTV, the value of β used is changed to 0.84 from its usual value of 1.64.

A combination of factors makes the impact of respiratory motion surprisingly small. The mid-ventilation technique means that the bulk of respiratory motion only blurs the dose distribution rather than producing a systematic shift. It can therefore be modelled as a random error. Further, the effect of all random errors, including respiratory motion, is minimised in this case by the large penumbral width (due to the target being surrounded by lung tissue) and the lower value of β due to the non-standard normalisation used in this SABR plan.

No ITV is used in this technique – the CTV from the mid-ventilation phase is directly grown to the PTV. If an ITV or moving CTV approach had have been used, the final PTV would have been considerably larger – 11.4mm larger in the superior-inferior direction.

We hope that our report provides a pragmatic set of useful tools to aid the radiotherapy professional in analysing sources of geometric uncertainty and calculating CTV-PTV margins consistent with successful radiotherapy treatment. ◘

***Dr Sam Tudor** is Consultant Clinical Scientist in Radiotherapy Physics at University Hospitals Birmingham NHS Foundation Trust*

All at sea

Eleanor May looks at how radiation protection advice enables military radiography.

I wonder how many of you have put on a hard hat, hi-vis jacket, safety boots and goggles to conduct a medical physics audit? That was my first experience of quality assurance (QA) testing a computerised tomography (CT) scanner. Did I mention – we were on a ship?

As a Trainee Medical Physicist at the Defence Science and Technology Laboratory (DSTL), along with my medical physics expert (MPE) mentor, I provide the medical physics and radiation protection advice to military healthcare. This includes both fixed establishments and deployed units, in this country and overseas.

Usually the environments and circumstances the military are faced with are unique and challenging. They often require innovative solutions distinct from those used in NHS trusts to maintain operational effectiveness, mitigating risks with practical approaches.

However, the difficulties posed by COVID-19 in the health service may present more parallels between the two contexts than ever before. Right down to rolling out Nightingale hospitals, our work may feel more familiar and tangible than you ever expected.

The problem

In deployed healthcare, an X-ray capability within the operational theatre saves lives. Medical care on the frontline has to combat the staggering volume, rapidity and severity of the incoming wounded, but with limited staff, resources and especially surgical capacity. Imaging is, therefore, crucial for clinicians to diagnose injuries accurately and efficiently, enabling rapid triage and effective treatment.

Our responsibility is their equipment: mobile X-ray ("heavier" and "lighter" X-ray sets can be chosen to fit the environment and mobility needs of a deploying unit), mobile fluoroscopy and containerised CT.

Our forces have to be agile to respond to a dynamic horizon of defence threats, meaning our medical support has to be agile too. This requires imaging modalities in field hospitals, which can be established in abandoned buildings to deserts. 1. Optionally, with CT scanners that fold down to be transported as a shipping container. And yes, even on ships – particularly the primary casualty receiving facility Royal Fleet Auxiliary (RFA) Argus. 2

In order to effectively protect our medical staff, military personnel and patients, common and established radiation safety procedures have to be adapted. Clinically, thresholds in triaging, justifications and decisions may have to be modified.

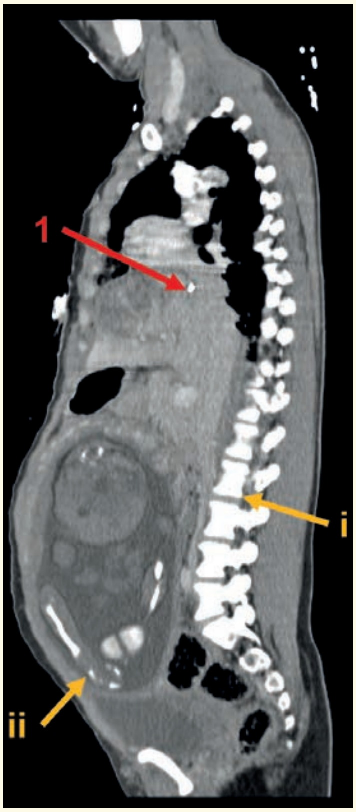
As medical physicists, this means that rather than determining the thicknesses of lead-lined walls, we are also dealing

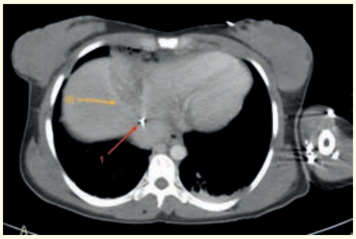
> **USUALLY THE ENVIRONMENTS THE MILITARY ARE FACED WITH ARE UNIQUE AND CHALLENGING**

❶ Field Hospital deployed on Exercise SHAMAL STORM, Jordan in 2016, who can be operational in under 16 hours.

❷ RFA ARGUS sailing to Sierra Leone with her crew of RFA, Royal Navy and Royal Marine Commandos in 2014 to assist in the Ebola crisis.

❸ CT of pregnant civilian in field hospital after sustaining blast injury: sagittal MPR (soft tissue window). Fragment in thorax (arrow 1); spine intact (arrow i); note foetus (arrow ii).





❹ CT of pregnant civilian in field hospital after sustaining blast injury: axial abdomen (soft tissue window). Fragment anterior to inferior vena cava (arrow 1); haemorrhagic wedge through liver due to perforation (arrow iii) (Centre of Defence Radiology.)

with tents and other temporary structures. Rather than space, we are balancing radiation protection requirements with the confinements of laydown size. Rather than one hospital, we are covering a country and beyond.

Case study

Consider this: a pregnant civilian is brought into the emergency department, having sustained significant blast, and associated fragment, injuries. CT would probably not be your first choice. But, you would also probably have options.

There would likely be an obstetrician on call, a specialised surgeon available and an incubator or surfactant to hand. From the examination there is clearly a high risk of head injury, bleeding in the abdomen and multiple other penetrating wounds.

You may consider laparotomy – but you are in a field hospital. You only have one theatre, the surgeon is generalised or orthopaedic and that would mean pre-term delivery. The chance of survival for the mother and unborn 24-week baby is extremely low.

So you need as much information as possible, as quickly as possible – 90% of deaths occur within the first 10 minutes of a blast, and you have many others to treat from the same incident.

After a number of plain chest X-rays and other tests, a CT examination is considered justified. In fact, 90% of patients involved in explosive blasts require CT.

And aren't you glad you did? Fortunately, the scans show the head injury to be manageable without surgery and no spinal fracture. ❸

Unfortunately, the imaging also reveals there is a fragment in the thorax – just in front of the vena cava. It is also clear that the fragment has already damaged the lungs and liver on its way and, if it moves anywhere, the risk of fatality is high. ❹

So what do you do now? You know operating would likely result in death, but is there an alternative? The confidence provided by the CT results means yes.

IMAGES: DEFENCE / CENTRE OF DEFENCE RADIOLOGY

You lay her head down for 48 hours. That way, the weight of the foetus will apply pressure to the liver, which will prevent further bleeding, mimicking the packing that would have been applied by surgical intervention.

This was a real incident and amazingly a full recovery was made. The patient was discharged after a week of further care, and two months later the hospital received a letter from her with thanks and news – the baby had been delivered safely at full term and both mother and baby were well.

This is just one of countless scenarios demonstrating the limitations faced by deployed healthcare and the importance of novel solutions that are required to enable vital military radiography in diverse clinical settings.

This same level of ingenuity and pragmatism is paramount in our own approach to medical physics and radiation protection advice.

The solutions

When an X-ray is taken vertically downwards in, say, the emergency department of a field hospital, a 2m distance in all directions must be cleared from medical staff not involved in the imaging.

As you can imagine, there is not much room for manoeuvre. So where that is not possible, say, in the radiography department, on our advice they now have portable and retractable lead screens – as is likely available when performing X-rays on wards in the NHS.

If an image is being taken horizontally however, say, across the pelvis when a patient cannot be moved, an area 8m in the direction of the X-ray, and 6m either side must be cleared.To avoid requiring sentries to manage such a large exclusion zone, we advise that the department be located against a solid structure. In lieu of buildings, a generator, Hesco bastion or sandbags could be used for shielding.

These measures ensure field hospitals are functional and compact, allowing them to be deployed into diverse environments.

"THIS IS JUST ONE SCENARIO DEMONSTRATING THE LIMITATIONS FACED BY DEPLOYED HEALTHCARE

Following a recent change to the air management in the chemical, biological, radiological and nuclear (CBRN) hospital, a problem was identified with the connections to the containerised CT scanner. Initial solutions would have resulted in unacceptable risk to personnel and potentially the removal of the capability.

We proposed the addition of louvred shielded vents to the scanner doors to restore airflow, whilst minimising the radiation hazard, thus keeping the CT scanner operational.

On ships, we have made recommendations at the design and installation stages to ensure appropriate shielding. Using existing steel construction where achievable, we also detailed additional lead-lining of bulkheads and decks where necessary.

Where it was previously infeasible to deploy small expeditionary forces into hostile areas without field hospital or allied force assistance, it is now possible with high-quality, image-informed surgical support at sea.

A day in the life

Starting in September 2019, my first visit was to 34 Field Hospital on a validation exercise. This means they set up as if deployed, and run through scenarios with simulated casualties. The applied and personal nature of our work has been a breath of fresh air – intellectually as well as physically!

I have been training on the job, after graduating in Physical Natural Sciences.

Alongside learning and courses, I really

❺ CT scanner and mobile fluoroscopy equipment lashed down in the radiology suite on-board RFA ARGUS.

❻ Medical equipment checks in the ship's hospital on board RFA Argus as it prepares to leave for Sierra Leone.

value building relationships with the military radiologists and radiographers. It is a privilege to be part of the team that keeps our forces operational and safe.

The breadth of our work and variety of advice is also fascinating. As well as RFA Argus another highlight has been visiting one of the nation's two aircraft carriers, HMS Queen Elizabeth.

On ships, I am always struck (if not by the low ceilings, or "deckheads") by the fact that everything has to be lashed down. Equipment has to be secured to prevent damage during transit, resulting in interesting requirements for procurement. ❺

A normal week has additionally consisted of anything from editing our QA spreadsheet for CT, to discovering there is a tortoise option on a Veterinary Centre X-ray set; designing e-learning for dental QA; reviewing research proposals to an ethics committee; creating a conditionally formatted spreadsheet for radiographers QA; rewriting local rules, safety procedures and systems of practice; replying to requests over email; proofreading research papers; organising urgent dosimetry to be delivered to a medical regiment before deployment…

Even preparing for a visit involves hotel bookings and hire cars, and many emails to organise timings and site availability. Conducting the visit usually involves a substantial drive, and then the report still needs to be written on your return.

All this only serves to make me value my job more. It is a joy and honour to be part of such a small team (only two!) within the wider Radiation Sciences Group at DSTL, and be responsible for such a crucial aspect of deployed healthcare, helping to protect our staff, military personnel and patients.

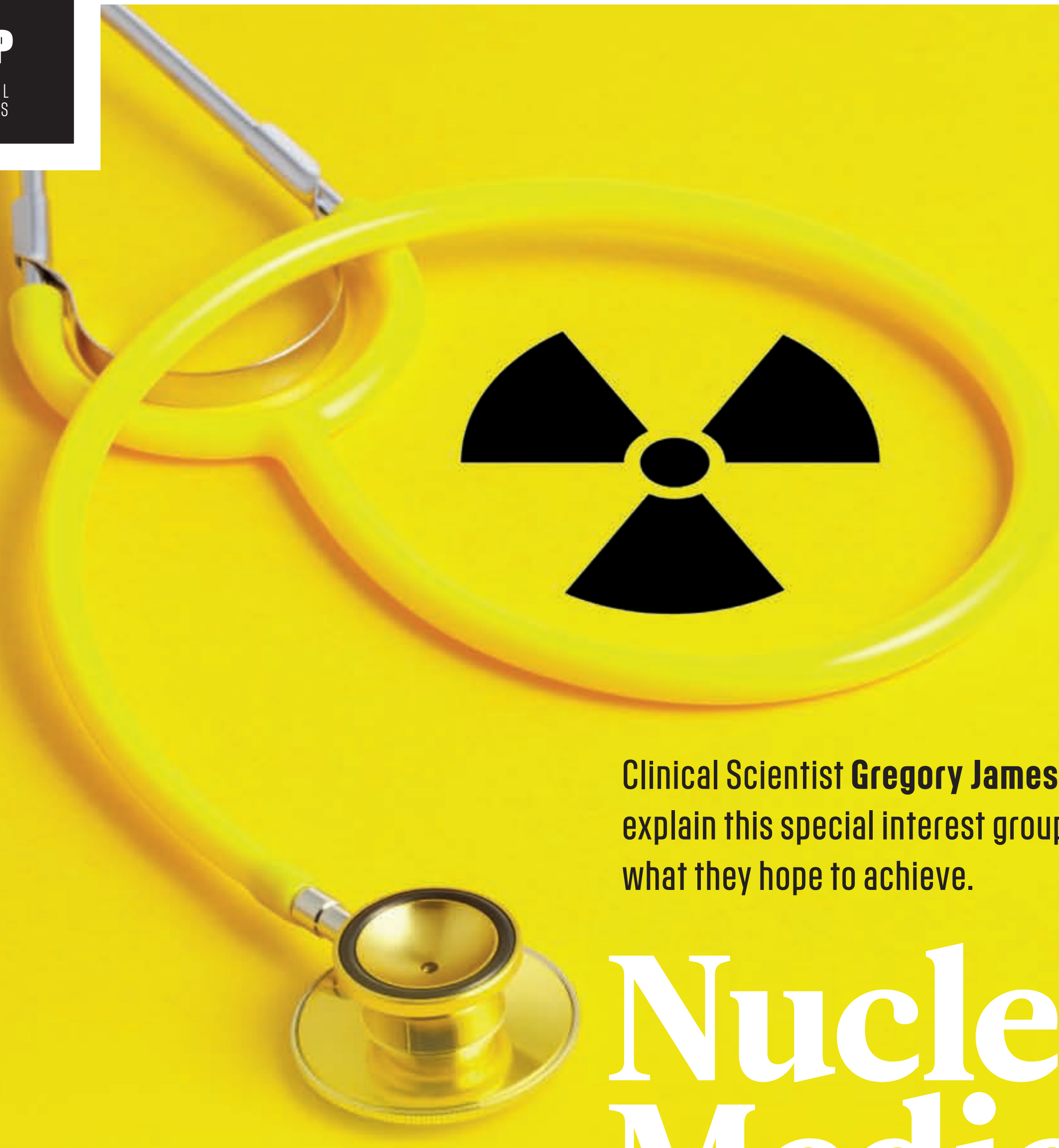
I wonder how COVID-19 has forced your medical physics services to adapt. I offered my skills when the Nightingale in London was initiated, but they already had enough help at the time. Maybe you were one of those who volunteered and provided crisis equipment support.

Maybe you are working from home, or developing new ways to gather audit data remotely. Maybe you are dealing with unfamiliar challenges, or managing quarantined CT scanners alongside high throughput.

However you are coping, and whatever lockdown has meant for your hospital, take encouragement – we are in it together. Radiation protection in diagnostic radiology can be functional and agile, whatever it is faced with.

Medical physics remains critical and challenge can be an adventure for our expertise. So when we feel all at sea we continue to anchor the healthcare our country desperately needs. ◘

***Eleanor May** is a Trainee Medical Physicist and Radiation Protection Support Technician at DSTL.* *She would like to thank the Centre of Defence Radiology for their assistance in compiling this article.*



Clinical Scientist **Gregory James** and colleagues explain this special interest group, why it exists and what they hope to achieve.

Nuclear Medicine Software Quality Group

Who, what and why?

Nuclear medicine involves the administration of radioactive tracers (radiopharmaceuticals) diagnosis or radiation therapy. The bio-chemical properties of the radiopharmaceutical cause it to accumulate somewhere in the body and the physical, radioactive properties of the radionuclide enable the distribution to be imaged with a gamma camera or positron emission tomography (PET)-CT scanner. Nuclear medicine is therefore a functional imaging modality which studies the physiology of the body. With any functional test, quantification is often used, which involves computer software to analyse the image data. For example, the uptake of [^{18}F]FDG in PET imaging is commonly measured using a standardised uptake value (SUV). Similarly, in myocardial perfusion imaging (MPI), software is commonly used to quantify the extent of ischaemia (reduced blood supply) in the myocardium (heart muscle). Following is an example:

Example quantification from a myocardial perfusion study

❶ The images to the right show a single tomographic slice through the left ventricle of the myocardium. The images should appear to be full circles, indicating good radiotracer uptake and, therefore, good blood supply throughout the whole myocardium. The images to the right highlight areas of the myocardium with abnormally low perfusion (blood supply) indicated by the black areas. In this example, the quantification software calculates that 17% of the total heart muscle is affected by reduced blood flow when the heart is in a state of stress. The images also show that the affected area is in the lateral wall where blood is supplied by the circumflex coronary artery. The software calculates that 3% of the defect is also present when the heart is in state of rest and so the reversible component is 14%. The so-called reversibility is important because the affected area(s) of the heart can be re-perfused with blood by inserting a catheter and stent into the defected coronary artery.

Software

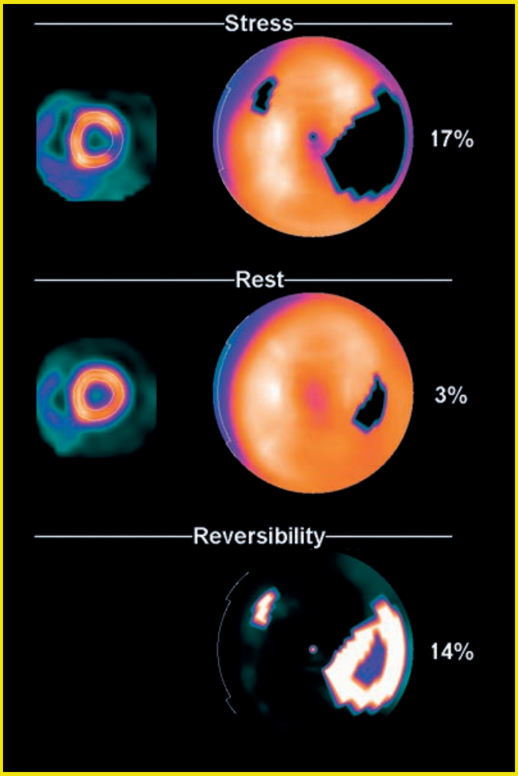
There can be multiple commercial software packages for a given clinical study to help users quantify radiotracer uptake. In the example shown in Figure ❶, there are at least three commercially available software packages to quantify myocardium uptake. For other studies software might not be available if there is no commercial interest, so nuclear medicine departments often use in-house, bespoke software programmes or spreadsheets to fill the gaps where no commercial solution exists. One of the key roles of the Nuclear Medicine Software Quality Group (NMSQG) is to provide data and a framework to allow departments to evaluate such software in an independent, consistent, and unbiased way.

Who we are

The NMSGQ is a subgroup of the IPEM Nuclear Medicine Special Interest Group (NMSIG). The NMSQG consists of up to eight members, including a chairperson and a secretary. Members are required to have experience in nuclear medicine software, either as a user or a developer. The group also engages with industry representatives either by reserving a seat on the group or by collaboration on projects. This can often provide useful insight into the commercial point of view of software development. Membership is for approximately three to four years and new members are recruited annually.

Working closely with the group are regional coordinators who assist in distributing data within certain regions of the UK. For example, the group might plan an audit and prepare data, which is distributed to all participating centres via the regional coordinators. The regional coordinators are also responsible for assisting the local departments with processing and data collection.

Figure ❶ Quantification from a myocardial perfusion study

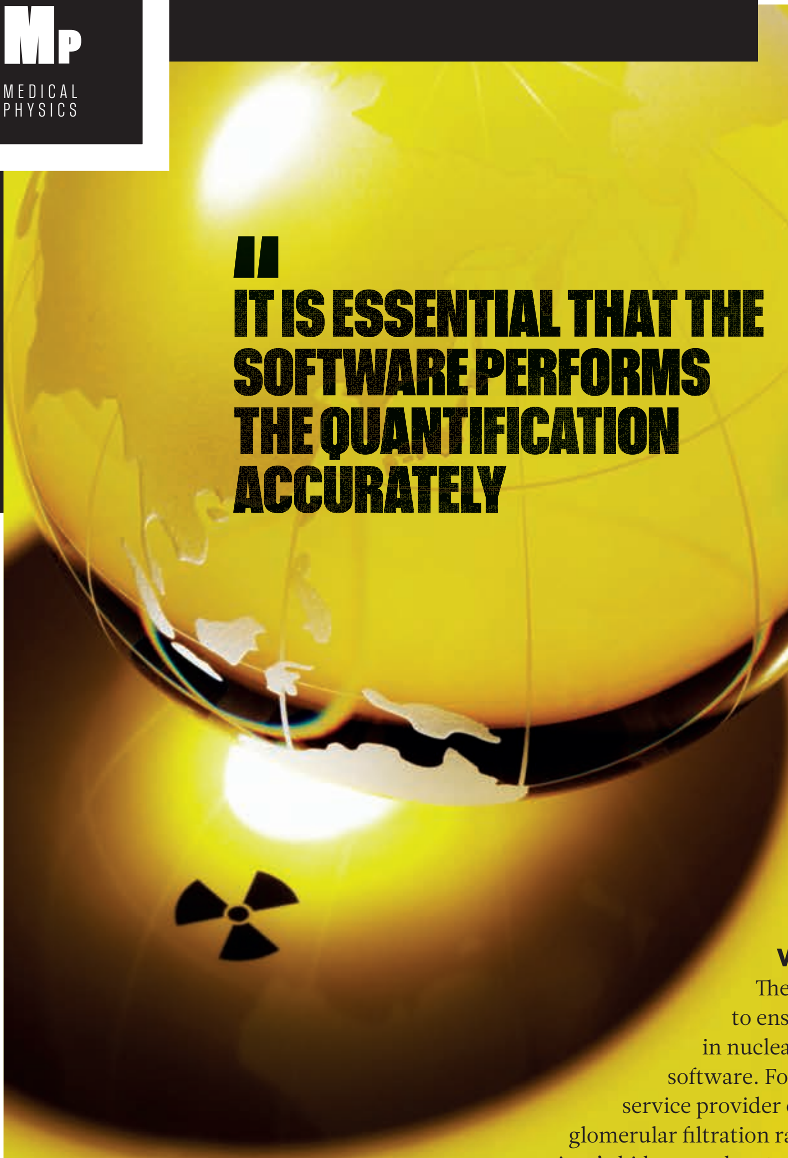


What we do

Audits are required under the Ionising Radiations (Medical Exposure) Regulations (2017) for optimisation and are one of the seven pillars of clinical governance. The NMSQG use audits as a mechanism to capture the practices of different departments and learn what software is being used. There is often a wide variation in techniques, protocols, and software between nuclear medicine departments, which can pose challenges. Last year the group carried out a survey of nuclear medicine departments to understand the variation in software currently used clinically in the UK. The results will be presented at the British Nuclear Medicine Society (BNMS) Annual Meeting.

The NMSQG typically provide anonymised clinical datasets to be distributed to participating centres via the network of regional coordinators. Participating centres are then asked to process the data according to their local protocol and report the results back to the NMSQG. The group will highlight any unusual results and communicate with the participating department. An issue with this type of audit is that it is often difficult to differentiate between abnormal results due to software error and abnormal results due to other factors, such as poor technique and operator variability. For this reason, more recently there has been a focus on developing manufactured datasets with a theoretically "correct" answer. For studies that don't require imaging, this is straightforward as it only requires the generation of representative numbers. A prime example is the calculation of glomerular filtration rate (GFR) where radioactive plasma samples are collected

IMAGES: GETTY



"IT IS ESSENTIAL THAT THE SOFTWARE PERFORMS THE QUANTIFICATION ACCURATELY

from the patient and counted on a sensitive radiation detector. Images are not involved and so this only requires the (careful) generation of numbers to provide a "model" dataset. The task of providing a "model" dataset becomes more difficult when generating gamma camera images or tomographic single photon emission computed tomography (SPECT)/PET data. The generation of such data can be achieved with Monte Carlo platforms, such as simulation of imaging nuclear detectors (SIMIND) or Geant4, in combination with image analysis platforms, such as MATLAB, Python or ImageJ. Modelling the complex physiology of the human body adds a final challenge that is especially difficult in dynamic studies where the distribution of radiotracer changes with time. The group is currently working on generating "model" data for gastric emptying studies and renograms using these techniques.

Why we do it

The group exists to ensure quality in nuclear medicine software. For example, if a service provider calculates the glomerular filtration rate (GFR) of a patient's kidneys to be 79 ml/min, it is important that this number is accurate and comparable to results that another centre would measure for the same patient. Errors in software used to calculate GFR could lead to patients receiving nephrotoxic chemotherapy drugs when their kidneys cannot tolerate the associated toxicity. Conversely, the patient could be wrongly denied treatment if the GFR is miscalculated as being too low.

The calculation of GFR in nuclear medicine is a clear example of why an audit cycle is required. Locally developed solutions for GFR calculation are common due to variations in practice and a lack of commercial options. Previous audits of GFR calculation by the group demonstrate the effectiveness of the audit cycle. In 2001, an audit was performed of GFR measurement, demonstrating significant variation in methodology and results obtained across the UK. Following new guidelines published in 2004, a re-audit was performed in 2013 demonstrating much improved standardisation. In particular, the adoption of early exponential clearance correction become almost ubiquitous (as recommended in the 2004 guidelines) compared to implementation by only half of the centres in 2001.

Where are we going?

Quantitative SPECT is becoming a hot topic in nuclear medicine; which is the ability to measure the activity of radiotracer inside a patient using tomographic gamma camera imaging. The main challenge with quantitative SPECT is that the uptake values are affected by many variables in the acquisition and processing of the data. With regards to acquisition, this includes choice of collimator, pixel size, energy window and angular sampling resolution, among others. At the data processing stage, the variables include reconstruction algorithm, filter settings and correction algorithms such as scatter correction, attenuation correction and resolution recovery. These factors will change the counts in the reconstructed tomographic data. Ultimately, a clinician might want to measure the uptake in a lesion to assess whether the patient has responded to treatment. It is therefore essential that the software performs the quantification accurately and the NMSQG have a role to play with independently testing such software.

One last thing...

The group advertises for new members on the IPEM website and the medical physics mail base. Please apply for membership if you are interested in working with the group. Please also take part in our audits, if invited to do so. Audits are an important way of assuring quality for the service provision of our patients. We look forward to inviting new members onto the group in the near future. For the latest news, upcoming audits, and results of the previous work of the group, please visit the website: **bit.ly/NMSQG**

***Gregory James**, Matthew Memmott, Jonathan Price, James Cullis, Mark Barnfield, Laura Perry and Mark Pether*

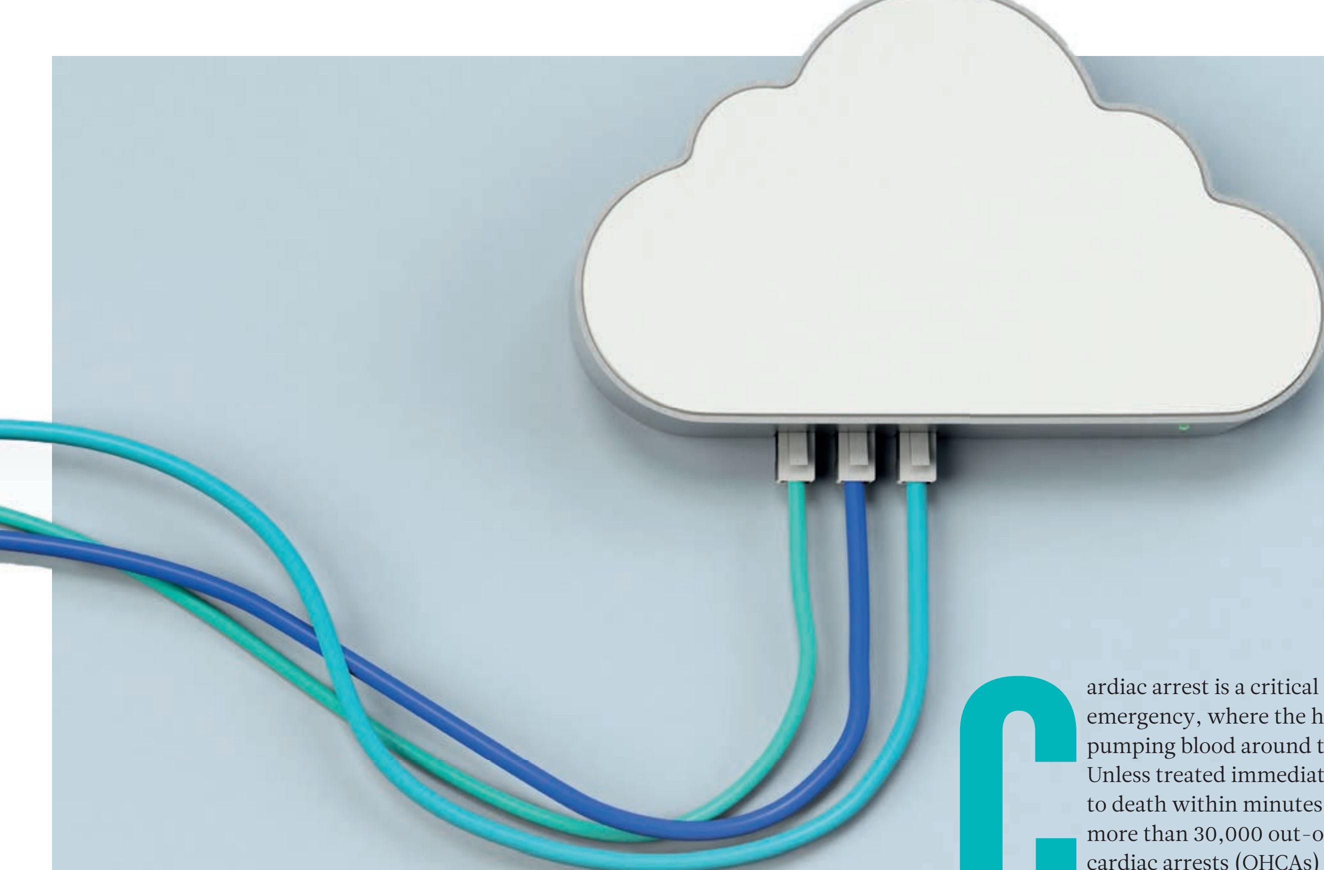


IMAGE: GETTY

INTRO-DUCING...

A cloud-based defibrillation system during COVID-19

Chris Hopkins, Consultant Clinical Scientist and Head of Clinical Engineering, Innovation and Research, outlines a new system that provides hospital teams with critical information on cardiac events.

Cardiac arrest is a critical medical emergency, where the heart stops pumping blood around the body. Unless treated immediately, it leads to death within minutes. There are more than 30,000 out-of-hospital cardiac arrests (OHCAs) in the UK each year and the overall survival rate in the UK is just 1 in 10. Every minute without cardiopulmonary resuscitation (CPR) and defibrillation reduces the chance of survival by up to 10% and performing CPR can more than double the chances of survival in some cases (ventricular fibrillation).

The Resuscitation Council made a number of changes to the guidance during the COVID-19 pandemic in order to help protect healthcare workers in hospital settings. The principle of "shock first" was introduced in an attempt to restore circulation as early as possible. The guidance recommended the wearing of Level 2 Personal Protective Equipment (surgical mask, gloves, apron and eye protection) when a defibrillator is available, and defibrillate shockable rhythms rapidly prior to starting chest compressions.Early restoration of circulation may prevent the need for further resuscitation measures.

What was the problem?

The change in the resuscitation guidance resulted in the clinical engineering team having to reconfigure over 269 defibrillators (a mix of manual and automated external defibrillators, AED's) across four acute hospitals and a number of community settings. This prompted us to consider alternative strategies to reconfigure devices in future through a cloud-based system.

Driven by the Resuscitation Guidelines (2015), which suggest data-driven performance-focused debriefing demonstrates an improvement in performance of resuscitation teams, Hywel Dda

University Health Board (UHB) began a comprehensive evaluation exercise, examining a number of defibrillator suppliers in the market place. A detailed specification was developed that looked at a number of key areas:

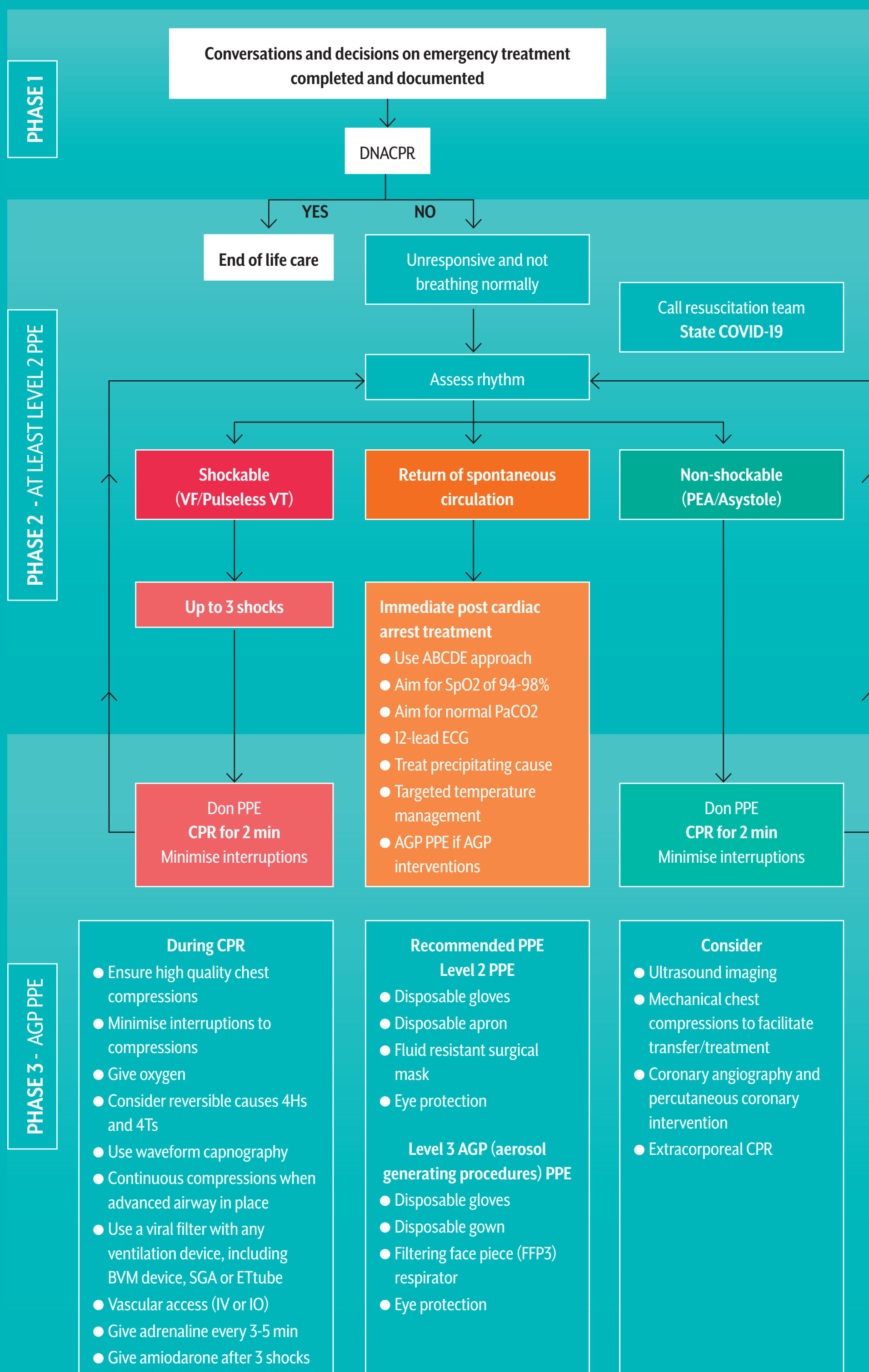
- Ability to wirelessly transmit device and patient data to a central location. A simple easy to read dashboard that delivers information in a timely manner:
  - Compression ratio
  - Compression rate
  - Compression depth
  - End-Tidal Carbon Dioxide (EtCO2) trend data
  - Chronological cardiac event logging.
- Ability to remotely configure changes through Wi-Fi that supports UK Resuscitation Council guideline changes
- Ability to provide feedback to clinical teams

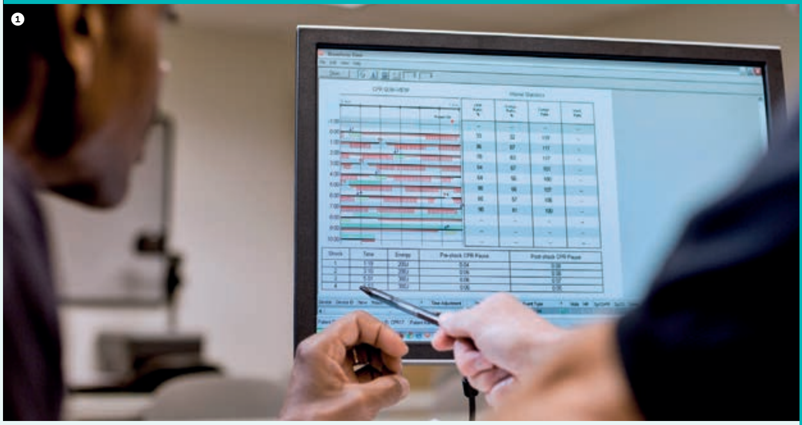
With this increased focus on quality, the UHB set out to improve practices and resuscitation data across all of its hospitals. The guidelines suggest data that is downloaded from defibrillators can provide valuable information in order to improve CPR performance long term.

A project to replace the UHB's ageing stock of 269 defibrillators is now underway. A multi-disciplinary team including informatics, clinical

> **"DATA THAT IS DOWNLOADED FROM DEFIBRILLATORS CAN PROVIDE VALUABLE INFORMATION**

ADULT ADVANCED LIFE SUPPORT FOR COVID-19 PATIENTS – ACUTE HOSPITAL SETTINGS





❶ Left: Resuscitation Council UK: Adult Advanced Life Support for COVID-19 patients – Acute hospital settings

engineers & infrastructure specialists was established to evaluate the 802.11 Wi-Fi infrastructure across the UHB. IT infrastructure was setup to allow automatic external defibrillators and manual defibrillators to sit within this wireless network, using Wi-Fi Protected Access 2 (WPA2) enterprise protocols. The defibrillators had the clinical configuration settings installed from multiple sites to one common setup, located on the cloud.

What were the results?

All defibrillators reside within the acute and community hospitals, but update to the Cloud and Health Board CodeSTAT server on a daily basis. Automated device self tests are undertaken at 3am every day and the results are uploaded to the cloud. Notifications are forwarded to the Clinical Engineering departments should any errors appear to allow immediate corrective actions to be undertaken. We now have the availability to:

- Wirelessly transmit device and patient data to a central location.
- Examine an easy to read dashboard that delivers information in a timely manner
  - Compression ratio
  - Compression rate
  - Compression depth
  - End-Tidal Carbon Dioxide EtCO2 trend data.
- Interrogate chronological cardiac event logging
- Remotely configure changes through Wi-Fi that supports UK Resuscitation Council guideline changes
- Provide feedback to clinical teams.

What are the learning points?

The guidelines call for compression fractions above 80% with compressions at 100-120/min. Hywel Dda UHB can now measure how we compare in terms of compression, ventilation rates and compression fraction to see our performance compared to Resuscitation Council standards across the UK. We can gather quantitative data from each event to show hands-on clinical teams how they performed and to show clinical leadership teams how the whole system is performing.

Our Clinical Engineers are now performing modifications and changes to the cloud-based system in order to improve functionality and availability of data. We will use the data gathered from the new cloud-based system to develop strategies that allow our clinical teams to streamline protocols and treatments, to help further improve practice in line with the Resuscitation Council guidelines. ○

Chris Hopkins is a Consultant Clinical Scientist and Head of Clinical Engineering, Innovation and Research at Hywel Dda University Health Board. *He would like to thank **Jon Wilson**, Principal Clinical Technologist at Hywel Dda University Health Board, Stryker UK and the Resuscitation Council UK for supporting this work.*

IMAGES: RESUS COUNCIL

The potential role of wearables in health monitoring is changing, but substantial challenges remain to realise their full potential, writes British Heart Foundation Research Fellow **Peter Charlton.**

REALISING THE POTENTIAL OF WEARABLES

The rapid development and widespread acceptance of wearables provides a new opportunity to monitor health in daily life. Wearables are now widely worn: one in five US adults say they regularly wear a smart watch or fitness tracker. Wearables are now capable of measuring a range of physiological parameters and signals. Researchers have proposed several clinical applications, with promising evidence for their potential utility. This article explores the potential role of wearables, and the steps required to realise this for health monitoring. Herein, wearables are defined as devices which attach to (and can be detached from) the body, acquire physiological measurements, and are physically disconnected from the external environment.

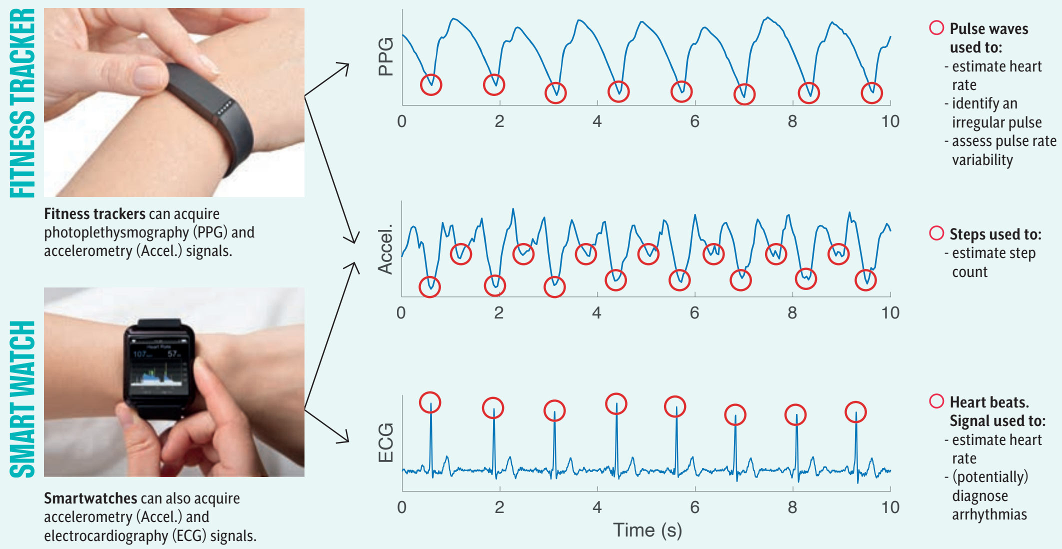
History of wearables

Wearable devices have been used for over half a century for cardiac diagnosis and monitoring. Devices for long-term, ambulatory electrocardiogram (ECG) recording emerged in the 1960s. Named "Holter" monitors, after a physicist pivotal to their development, the devices allowed infrequent ECG abnormalities to be identified retrospectively by reviewing recordings. In the 1980s the technology was extended to develop telemetry monitors which not only monitored the ECG continuously, but also transmitted it in real-time to a central monitoring station. Telemetry systems are used to this day, allowing life-threatening arrhythmias to be identified and acted upon quickly.

Three key advances in wearables in the past decade have greatly increased their potential utility: expanded functionality, miniaturisation, and availability on the consumer market.

The functionality of wearables has expanded to monitor additional vital signs beyond heart rate and rhythm. For instance, hospital telemetry devices can now also monitor blood oxygen saturation and respiratory rate. Wearables have been miniaturised sufficiently so that they can now be attached directly to the patient without needing to carry the device in a pouch or pocket: long-term ECG recorders can now be worn as chest-patches, about the size of a small box of matches. Wearables have also become widely available on the consumer market, opening up the potential for self-monitoring outside the healthcare setting.

Figure 1 The physiological signals commonly acquired by wearables



Fitness trackers can acquire photoplethysmography (PPG) and accelerometry (Accel.) signals.

Smartwatches can also acquire accelerometry (Accel.) and electrocardiography (ECG) signals.

Current functionality

Current wearables use a range of sensors to provide detailed physiological measurements (see Fig. 1).

Heart rate is commonly monitored using photoplethysmography. This technique consists of shining light on a tissue (typically using an LED), and measuring the amount of light transmitted or reflected back to a light sensor. The resulting signal exhibits pulse waves caused by the increase and decrease in arterial blood volume with each heart beat. Wearables – such as fitness bands, smart rings, and smart watches – use this approach to monitor heart rate, heart rhythm, and heart rate variability (which can provide insight into sleep and stress). In addition, devices such as the Apple Watch now use multi-wavelength photoplethysmography to provide blood oxygen saturation measurements.

> **"KEY ADVANCES IN WEARABLES IN THE PAST DECADE HAVE GREATLY INCREASED THEIR POTENTIAL UTILITY**

Activity is monitored using accelerometry. Movements are detected by using force sensors to measure accelerations, and the resulting signals can be used to monitor activity levels. Activities such as walking or cycling produce regular fluctuations in the signal which can be analysed to automatically identify the activity type, and can be used to estimate measurements such as step count.

In an exciting step forward, some watches can now be used to acquire ECG recordings. An ECG is recorded between the two arms using one electrode on the underside of the watch, and a second electrode on top which the user holds with their opposite hand. The recording provides a similar view to a lead I ECG recording, albeit measured further away from the heart.

IMAGES: ISTOCK / SHUTTERSTOCK

Landmark studies

Several large-scale studies provide promising directions to capitalise on smart wearables for health monitoring.
One of the most promising applications is identifying atrial fibrillation (AF). AF is a common heart arrhythmia that confers a fivefold increase in stroke risk. AF can occur intermittently and asymptomatically so often remains undiagnosed. Wearables provide opportunity to identify potential AF by identifying an irregular heart rhythm, as shown in Fig. ❷. In the Apple Heart Study, notifications of an irregular pulse generated from an Apple Watch using photoplethysmography identified AF with a positive predictive value of 78% (in subjects aged over 65.

The Huawei Heart Study and the ongoing FitBit Heart Study provide complementary research. However, it is not yet clear how sensitively photoplethysmography-based wearables detect AF, nor whether AF detected in this manner should be treated in the same way as AF detected in routine practice. The new ability to record ECGs provides opportunity to use smart watches not only to identify possible AF episodes, but also to prompt the user to take an ECG recording during such episodes, which could be used to confirm an AF diagnosis.

COVID-19

Early detection of COVID-19 is key to reducing transmission, particularly in asymptomatic individuals. A recent study by Scripps Research indicated that models to identify COVID-19 from self-reported symptoms can be improved by incorporating wearable data. A model using wearable data alone (resting heart rate, sleep duration, and step count) provided similar performance to one using symptom data alone, and performance was improved when using both data sources. A separate Stanford University study demonstrated that the same wearable variables could be used to identify a subset of COVID-19 cases before or at symptom onset. Potentially, wearables could be used to monitor continuously for COVID-19 across a large portion of the population, complementing tests conducted at limited time points in certain individuals. This builds on previous research demonstrating the potential utility of wearables for tracking trends in influenza-like illnesses across the population.

Ongoing studies

Much further work is required to realise the potential of wearables. In the UK Biobank Cardiac Project, participants are asked to wear an ambulatory ECG recorder in the form of a chest-patch for two weeks. The data collected will be valuable for research into the impact of intermittent arrhythmias on health, particularly when coupled with heart and brain scans.

There is much incentive for using wearables to monitor acutely-ill hospital patients to identify early signs of deterioration. The EU-funded Nightingale project challenged industry to develop unobtrusive wearables for frequent vital signs monitoring, and assessed their performance in multiple hospitals across Europe. Researchers in Oxford have been developing and testing the concept of a virtual High-Dependency Unit, which may have particular utility for monitoring mobile COVID-19 patients. In the future, it may be possible to use wearables to continuously update patients' NEWS scores, potentially providing earlier warning of deteriorations than routine observations which are usually conducted every four to six hours.

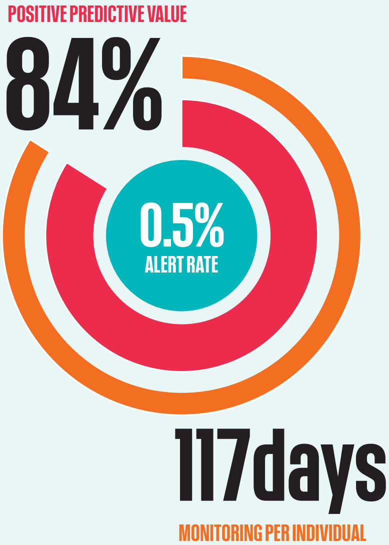
Future developments

Much research is focusing on using wearables for unobtrusive blood pressure (BP) monitoring. Some wearables use a cuff to measure BP, although such devices are often cumbersome and only allow intermittent BP monitoring. An alternative approach is to estimate BP from the arterial pulse wave, exploiting the relationship between BP and arterial stiffness. Firstly, pulse waves travel quicker in stiffer vessels, and so the time taken for the pulse wave to travel from the heart to the periphery is affected by BP. This time delay can be approximated as the delay between the heart beating (measured from the ECG) and the arrival of the pulse wave (from photoplethysmography). Secondly, the shape of the pulse wave is influenced by the vasculature, and could therefore be used to identify changes in BP. Such techniques may also provide insight into arterial stiffness, an

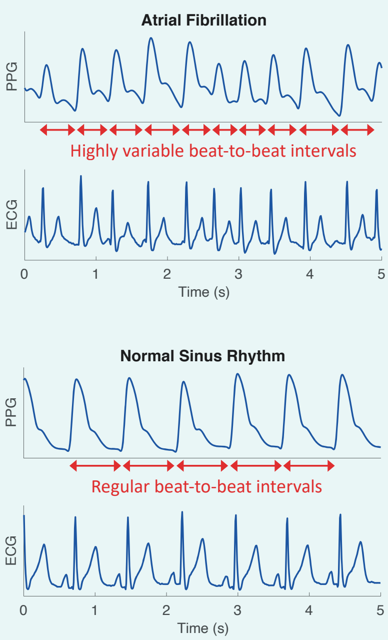
Figure ❷ Using wearables to identify possible atrial fibrillation.

Atrial fibrillation is an arrhythmia which causes irregular beat-to-beat intervals. Consequently, it can be identified from wearable signals. The Apple Heart Study assessed the performance of Apple Watches for detecting possible episodes of atrial fibrillation in 419,297 individuals.

Key results included:



SIGNALS FROM THE LISTEN DATASET



emerging marker of cardiovascular health.

Research is also investigating additional clinical use cases for wearables, such as identifying obstructive sleep apnea (OSA). OSA is a common and under-diagnosed cause of sleep disturbance and daytime tiredness, which can increase cardiovascular risk and the risk of road traffic accidents. Consumer wearables may have utility for identifying possible OSA given their ability to track sleep and oxygen saturation. Individuals identified as having possible OSA could be referred for a sleep study to confirm a diagnosis.

> **" POTENTIALLY, WEARABLES COULD BE USED TO MONITOR CONTINUOUSLY FOR COVID-19**

Challenges

There are several technical challenges to realising the potential of wearables. Firstly, wearables must be comfortable and unobtrusive enough to be accepted by patients and consumers. There have been great advances in this area with the advent of modern smartwatches and fitness trackers. However, it is still a challenge to maintain an acceptable form factor whilst increasing functionality to monitor additional parameters such as blood pressure. Secondly, algorithms for analysing wearable data must take into account the context in which the data were acquired. For instance, a heart rate of 110 beats per minute has very different implications if it is recorded from someone who has just climbed three flights of stairs, compared to someone recovering from major cardiac surgery at home. Whilst this challenge is evident in clinical practice (consider white coat hypertension), it is amplified in home-monitoring. Thirdly, alerts provided by wearables must be sufficiently accurate to ensure they are clinically useful. The false alert rate was reassuringly low in the Apple Heart Study, representing a significant achievement in wearable design.

There are also clinical challenges to realising the potential of wearables. Firstly, it is important to identify specific use cases where wearables could provide clinical benefit. Typically, these fall into the categories of either identifying an under-recognised disease, or providing continuous physiological monitoring in settings where measurements could otherwise only be taken intermittently. Secondly, effector limbs must not be overly burdensome. For instance, if a consumer wearable detects AF in someone aged over 65, then perhaps they could be offered an ECG-based wearable to confirm the diagnosis with minimal input required from clinicians. Thirdly, any use of wearables in clinical practice must be cost-effective, and must therefore be coupled with an effective intervention to modify patient outcomes. AF is a prime example of a condition where there is a highly effective treatment which improves outcomes, which can be initiated based on a diagnosis from wearable data.

Outlook

The use of wearables for health monitoring is delicately poised. Wearables have potential to provide early detection of under-recognised conditions. However, there is a danger they may also provide inaccurate information, prompting unwarranted and costly clinical follow-up and even intervention. Therefore, there is an ongoing need for engineers, physicists and data scientists to work closely with clinicians and medical researchers to ensure the full potential of wearables is realised for the benefit of patients. ◘

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BOOK PITCH

A problem-solving approach

Gavin Poludniowski outlines the approach of a new book that he has co-edited about radiology physics and MATLAB.

I'd like to introduce you to a book that I edited with two colleagues. It's called *Diagnostic Radiology Physics with MATLAB: a problem-solving approach*. It's published by CRC Press. This isn't a book providing a comprehensive introduction to MATLAB. There are other books for that. Nor is it a book on image-processing. There are other books for that. And despite the word "physics" in the title, it's not a book about the physical principles underlying radiology. You guessed it – there are other books for that too.

Here's the pitch. Our book focuses on providing readers with practical skills for implementing MATLAB as an everyday tool, rather than on solving academic and abstract problems. Further, it recognises that MATLAB is only one tool in a medical physicist's toolkit and shows how it can be used as the "glue" to integrate other software and processes together. Yet, with great power comes great responsibility. The pitfalls to deploying your own software in a clinical environment are also clearly explained. This book is for all medical physicists and medical professionals looking to learn how to utilise MATLAB in their work.

Despite the title, we have not provided a large set of problems for the reader to solve themselves. Rather, we have provided examples of how other people have solved their problems. This includes a variety of relatively short examples in the first part of the book and in-depth case studies in the second part (11 of them). Note that the authors of the case studies are not software engineers: the code was written primarily by medical physicists, for medical physicists. The code has the great virtue that it does the job. There are real benefits from adopting good practices, however, and there are times when software must be developed to industry standards. This is also covered.

> **"IT RECOGNISES THAT MATLAB IS ONLY ONE TOOL IN A MEDICAL PHYSICIST'S TOOLKIT**

There is no special reason why we chose MATLAB. But MATLAB has been around for over 30 years. It's a mature product with powerful functionality, packaged with a large and ever increasing collection of "toolboxes". The core programming language and desktop environment are simple, powerful and relatively easy to get started with. It's a bonus that it's widely used and many of us have experience of using it from our university studies.

I'm not going to tell you that the book is good. Of course, I think it is, but I'm biased. But I can honestly say two things. Firstly, in editing the book, it was a pleasure to learn from knowledgeable chapter authors from around the world. And secondly, I wish this book had existed when I was first learning to apply programming to real problems.

All the MATLAB code discussed in the book is made available to the user for free in a software repository **bit.ly/3tk5ZT8**. Take a look at the repository, if you like. Or find the book here: **bit.ly/39KQrjr**.

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