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Volume 31 | Issue 4 | Winter 2021

IPEM

SCOPE

GOING GREEN

The debate on sustainability in healthcare and science

PRETERM BIRTHS

The power of AI prediction machines to avoid misdiagnosis

MEDICAL IMAGING

Rethinking technology and processes for a post-pandemic world

PERSONAL PROTECTION

Joining forces to deliver 400,000 pieces of PPE to the front line

FUNCTIONAL MRI

How to engage patients and collect reliable data with confidence

CHAIR OF IPEM SCOPE EDITORIAL ADVISORY BOARD

The last issue of the year

Usman Lula outlines the content in the latest issue of *Scope*, which is based around technologies, techniques and workflows.

Welcome all to the final issue of *Scope* in 2021. What a year this has been, with all the havoc COVID has caused to our lives and the lives of our loved ones. Let's hope that this winter doesn't spark a new wave that is not manageable with our best defence – vaccines.

In recent years we've been hearing more and more about climate change, its impact and how we plan to address the imminent issues. To get further traction on this topic, we thought we would first bring you a relevant debate around sustainability in healthcare and science. What role are we playing in helping the broader aims of fighting climate change? Three experts look at how the NHS net zero framework is helping us meet these needs. Have a read of the Big Debate section for more information.

Our theme in this issue was "technologies, techniques and workflows", and we certainly have some excellent submissions on these topics. To start with, Danielle Watson, an Apprentice Radiotherapy Engineer, talks through her valuable project based around improving efficiencies in collaboration with a manufacturer. It really shows that with the right investment, and support, our apprentices can really pave the way to better services. Another interesting feature is by John Tracey and colleagues, who looks at the role of AI in automated quality assurance and how to train neural networks. The key to his project's success was to have properly curated data, which is rigorously validated, alongside testing the accuracy of the algorithm and then comparing that with human efforts.

> Three experts look at how the NHS net zero framework is helping us meet the broader aims of fighting climate change

In late September, I received an email via IPEM's Chief Executive Phil Morgan from Ben Metcalfe, Director of Studies, Centre for Biosensors, Bioelectronics and Biodevices at the University of Bath, to include a feature around the involvement that universities had in supporting hospitals during the pandemic – specifically, to highlight how biomedical academics were able to work with hospitals. Ben himself was chatting to Mark Tooley who had suggested this as a *Scope* feature (thanks Mark!). After a discussion with Ben, we were able to agree on at least a two-part series on "collaboration in the pandemic", starting with this issue.

Have a great festive season and a happy 2022.

Usman Lula
Chair of IPEM *Scope* EAB

CONTENT

Ideal submissions

We recently welcomed Natasa Solomou as a new member on our *Scope* Editorial Board. She will be assisting us in meeting our strategic goals for all things *Scope*, especially improving the quality of contents. On quality, I have been pestering Rob (our editor) on what an ideal submission could look like – as he has vast knowledge around this area (and to prove this he has won numerous awards!). He has promised me a "spec" so I await his email! In time, we hope to update our author guidelines to ensure that we continue to improve variety in submissions as well as better convey our messages.

IPEM
Institute of Physics and Engineering in Medicine

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IPEM Fairmount House, 230 Tadcaster Road, York, YO24 1ES
T: **01904 610821** | F: **01904 612279**
office@ipem.ac.uk | **ipem.ac.uk** | **scopeonline.co.uk**

Chair of IPEM *Scope* Editorial Advisory Board: **Usman I. Lula**
Principal Clinical Scientist, 1st Floor, Radiotherapy, Building, Medical Physics – University, Hospitals Birmingham NHS Foundation Trust, Queen Elizabeth Hospital, Queen Elizabeth Medical Centre, Birmingham, UK B15 2TH
0121 371 5056 | **usman.lula@uhb.nhs.uk**

Commissioning Editor
Ejay Nsugbe

Commissioning Editor
Clara Ferreira

Commissioning Editor
Natasa Solomou

Commissioning Editor: **Dr Paul Doolan**
Medical Physicist, German Oncology Center, 1 Nikis Avenue, 4108 Agios Athanasios, Limassol, Cyprus
00357 2520 8025 | **paul.doolan@goc.com.cy**

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+44 (0)20 7880 6200
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Publisher: Daniel Butcher
daniel.butcher@redactive.co.uk | +44 (0)20 7324 2728

Editor: Rob Dabrowski

Lead designer: Carrie Bremner

Picture researcher: Claire Echavarry

Production: Aysha Miah-Edwards
aysha.miah@redactive.co.ukk | +44 (0)20 7880 6241

Advertising sales:
scope@redactive.co.uk | +44 (0)20 7880 7556

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COVER FEATURE

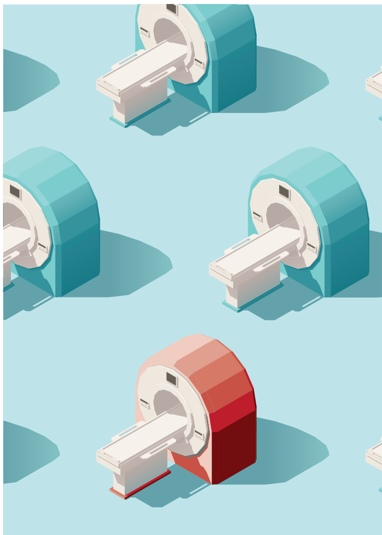
Following the COP26 UN Climate Change Conference in Glasgow, three IPEM members discuss what action they are taking in their respective sectors, the environmental legacy of COVID-19 and how to embed sustainability more effectively in their departments and in the NHS more broadly.

> The reduction in costs and environmental impact with improved patient service is a great achievement.

– *Laura Perry* page 14

UPFRONT

Cover image by
ISTOCK



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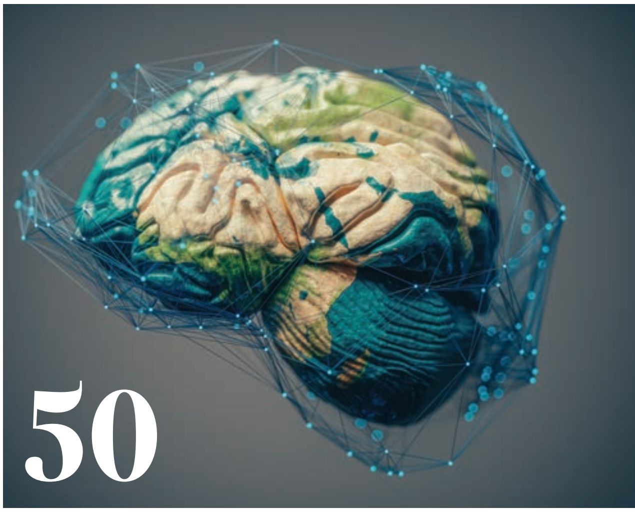
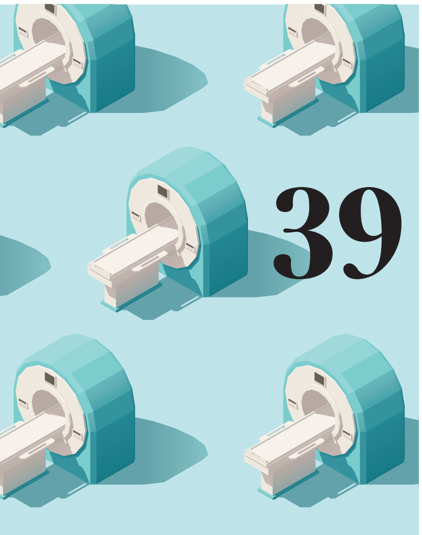
GENERAL





ENDNOTES

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UPFRONT

X-RAYS

Revolutionary imaging technology

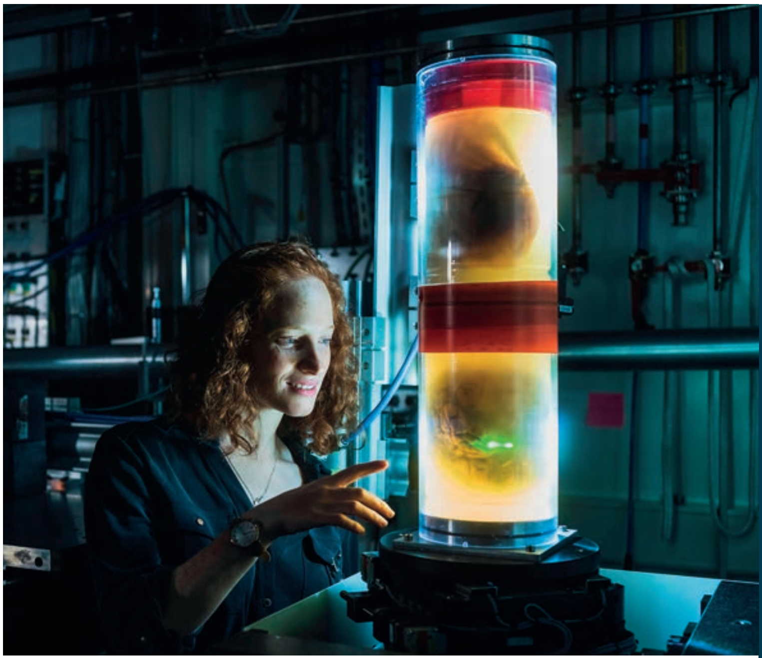


IMAGE: UNIVERSITY COLLEGE LONDON

> HiP-CT allows us to view the whole organ as never before by imaging it as a whole and then zooming down to cellular level

Scientists have used a new revolutionary imaging technology – hierarchical phase-contrast tomography (HiP-CT) – to scan donated human organs, including lungs from a COVID-19 donor.

The team from University College London and the European Synchrotron Research Facility (ESRF) used HiP-CT to enable 3D mapping across a range of scales.

This allows clinicians to view the whole organ as never before by imaging it as a whole and then zooming down to cellular level.

The technique uses X-rays supplied by the European Synchrotron (a particle accelerator in Grenoble, France), which, following its recent Extremely Brilliant Source upgrade (ESRF-EBS), now provides the brightest source of X-rays in the world at 100 billion times brighter than a hospital X-ray.

Due to this intense brilliance, researchers can view blood vessels five microns in diameter (a tenth of the diameter of a hair) in an intact human lung.

Co-author Dr Claire Walsh said: "The ability to see organs across scales like this will really be revolutionary for medical imaging. As we start to link our HiP-CT images to clinical images through AI techniques, we will – for the first time – be able to highly accurately validate ambiguous findings in clinical images.

"For understanding human anatomy this is also a very exciting technique. Being able to see tiny organ structures in 3D in their correct spatial context is key to understanding how our bodies are structured and how they therefore function."

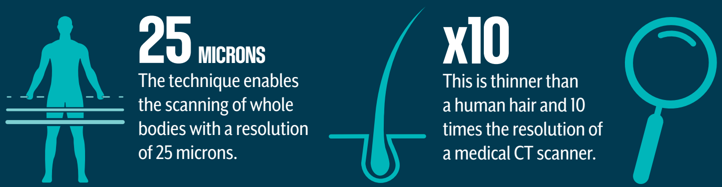
Using HiP-CT, the research team has seen how severe COVID-19 infection 'shunts' blood between two separate systems – the capillaries that oxygenate the blood and those which feed the lung tissue itself.

Such cross-linking stops the patient's blood from being properly oxygenated, which was previously hypothesised but not proven.

The researchers are confident that the scale-bridging imaging from whole organ down to cellular level could provide additional insights into many diseases such as cancer or Alzheimer's disease.

go.nature.com/2ZVhMwQ

FAST FACTS



25 MICRONS
The technique enables the scanning of whole bodies with a resolution of 25 microns.

x10
This is thinner than a human hair and 10 times the resolution of a medical CT scanner.

x100
Areas can then be zoomed in on, achieving local micron resolution, or 100 times the resolution of medical CT.

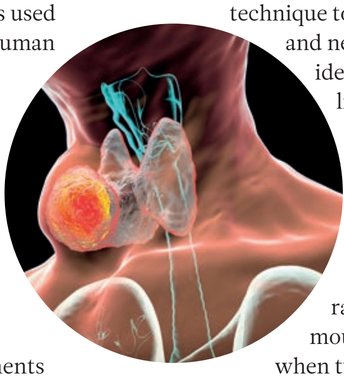
ONCOLOGY

Towards personalised radiotherapy

A new study identifies tumour features that are linked with resistance to radiotherapy.

The authors say this is an important advance toward developing individualised cancer treatments.

The team of scientists used mouse and lab-based human cell experiments to pinpoint mutations in two genes that drive radiation resistance in head and neck tumours and identified a drug that rendered resistant cancer cells sensitive to radiotherapy.



In the future, treatments could be tailored to patients with specific tumour types to improve responses to radiotherapy, they say.

Senior author Heath Skinner said: "The goal of this study was to link tumour genomics with response to radiation to figure out how we can make radiotherapy work better for patients."

Skinner and his team developed a technique to quickly screen head and neck cancer tumours to identify genetic targets linked with resistance to radiation.

They found that inhibiting proteins called CBP and p300 dramatically increased tumour sensitivity to radiation and improved mouse survival, but only when tumours had certain mutated versions of these proteins, indicating that these mutations may drive radiotherapy resistance.

go.nature.com/3k1PCaQ

COMPUTER SCIENCE

ALGORITHM PREDICTS TEEN SUICIDE

Researchers have created an algorithm that can predict suicidal thoughts and behaviour among adolescents with 91% accuracy.

A new paper outlines their machine learning approach and details risk factors that are leading predictors of suicidal ideation and behaviour among US adolescents: online harassment and bullying.

The study results show researchers can predict with high accuracy which adolescents will exhibit suicidal thoughts or behaviour.

The team analysed data from 179,384 junior high and high school students, along with those who participated in the Student Health and Risk Prevention survey from 2011 to 2017. The dataset contained a total of 1.2 billion data points.

Researchers then applied various algorithms to the data and found a machine-learning model that accurately predicted which adolescents went on to have suicidal thoughts and behaviours.

bit.ly/3ELh98p

NEWS IN BRIEF

Gait database

The Gutenberg Gait Database – the world's largest collection of gait analysis data of healthy individuals – has been published. The publicly accessible database provides a reference set of data to be used for the diagnosis and treatment of gait disorders, and further expansion of the database is planned. The database comprises data from 350 healthy volunteers who attended the biomechanics lab at Johannes Gutenberg University Mainz over the past seven years.

bit.ly/3wi1TwX

AI for diagnosing colorectal cancer

Artificial intelligence can accurately detect and diagnose colorectal cancer from tissue scans as well or better than pathologists, according to a new study.

Scientists collected over 13,000 images of colorectal cancer from 8803 subjects and 13 independent cancer centres in China, Germany and the US. Using the images, they built a machine-assisted pathological recognition program. The average pathologist scored .969 for accurately identifying colorectal cancer manually. The average score for the program was .98.

go.nature.com/3CNqzjh

Urine biomarker pilot study

Researchers at the University of East Anglia have shown that a prostate cancer urine test can identify men at 'intermediate risk' who can safely avoid immediate treatment and benefit from 'active surveillance' instead.

A new pilot study reveals how urine biomarkers can show the amount of significant cancer in a prostate, highlighting with more certainty which men need treatment.

bit.ly/3nV7sxj

DIAGNOSTICS

Test for antibiotic resistance in 90 minutes

A technique that measures the metabolic activity of bacteria with an electric probe can identify antibiotic resistance in less than 90 minutes – a dramatic improvement from the one to two days required by current techniques.

This means that doctors could quickly know which antibiotics will or won't work for a patient's life-threatening infection.

A Washington State University research team reports on their work in the journal *Biosensors and Bioelectronics*.

Douglas Call, a Regents Professor and co-author of the paper, said: "The idea here is to give the doctors results much more quickly so that they can make clinically appropriate decisions within that timeframe that they're working, rather than having to wait.

"Instead of looking for growth of a culture, we look for metabolism, and that is basically what we're detecting by the movement of these electrons so it can happen in much shorter time spans compared to a conventional culture-based assay."

The researchers are now planning to engineer their probe to be convenient and standardised for clinicians.

bit.ly/3k8sebL

UP CLOSE

DEEP BRAIN STIMULATION

WHAT IS DEEP BRAIN STIMULATION (DBS)?

It is a neurosurgical procedure involving placement of a neurostimulator (sometimes referred to as a 'brain pacemaker'), which sends high-frequency electrical impulses through implanted electrodes to areas in the brain responsible for the symptoms of disorders.

WHICH DISORDERS?

Movement disorders, such as Parkinson's disease and dystonia. DBS is for patients who have become non-responsive to medical management.

WHAT ARE THE LIMITATIONS OF DBS?

It masks the symptoms, but cannot fix the underlying problems.

SOUNDS LIKE IT HAS LIMITED SCOPE.

Yes, but new reports on a new approach in relation to Parkinson's have been published which state that after 30 minutes of stimulation, the stimulator can be left off for hours without symptoms returning.

WHAT DID THEY DO DIFFERENTLY?

The researchers used brief bursts of stimulation rather than continuous stimulation, as used during conventional DBS, and found that they could drive a specific pattern of neural activity that can induce long-lasting therapeutic responses.

WHAT NEXT?

The scientists behind the work want to study the short-term and long-term effects of burst DBS throughout the motor system.

bit.ly/3EJtNET

IMAGES: WSU / SPL / SHUTTERSTOCK

MEDICAL PRODUCTS

'EXTENSIVE NETWORK' OF INDUSTRY TIES

The medical product industry maintains an extensive network of financial and non-financial ties with all major healthcare parties and activities, reveals a new study.

This network seems to be mostly unregulated and opaque, and the paper in the *BMJ* calls for enhanced oversight and transparency "to shield patient care from commercial influence and to preserve public trust in healthcare".

The full extent of industry ties is still uncertain. To address this gap, the team of US researchers set out to identify all known ties between the medical product industry and the healthcare ecosystem.

They searched the medical literature for evidence of ties between pharmaceutical, medical device and biotechnology companies, and activities in the healthcare ecosystem.

Data in 538 articles from 37 countries, along with expert input, was used to create a map depicting these ties.

These ties were then verified, catalogued, and characterised to ascertain industry ties and policies on conflict of interests.

The results show an extensive network of medical product industry ties – often unregulated and non-transparent – to all major activities and parties in the healthcare ecosystem.

bit.ly/3qlkE1B

BIOENGINEERING

NOVEL OPERATING ROOM TECHNOLOGY

The Zucker Institute for Applied Neurosciences has partnered with South Carolina company Medical Access Partners to commercialise VayuClear – a novel surgical suction de-clogging technology.

In many surgeries, a narrow suction tube, with a metal or plastic tip on the end, is attached to a vacuum. This device is commonly used during operations to keep the surgical area free of blood, tissue and other surgical by-products.

Unfortunately, these devices tend to clog during surgery and VayuClear, invented by neurosurgeon Stephen Kalhorn, is intended to address this.

Designed to de-clog surgical suctions safely in one to three seconds via pressurised saline and a patented clearing mechanism, VayuClear will minimise frustration and let the surgical team stay focused on the patient and efficiently completing surgeries.

"We commonly see clogged suction lines and suction tips during operations, leading to delays," says Kalhorn. "Delays in surgery are frustrating and mean more time under anaesthesia for the patient."

Medical Access Partners is now in a round of investment funding, aiming to lock in manufacturing partners by the end of 2021.

bit.ly/3k7z2X1

BACTERIAL INFECTIONS

Quick, simple wound infection tests

A new spin-out company is being launched to create a quick and simple test for diagnosing bacterial infections in wounds.

SmartWound Limited's technology uses a colour-changing dye to diagnose bacterial infections from wound swab samples, specifically detecting when toxic bacteria are present without responding to the 'good' microbes normally found on healthy skin.

The University of Bath and University Hospitals Bristol and Weston NHS Foundation Trust are behind the new technology.

A proof-of-concept study in a small group of patients performed at the Bristol trust and at Queen Victoria Hospital in East Grinstead showed good accuracy.

The test is quick and simple to use and does not need to be sent off to a laboratory for processing, meaning clinicians can potentially spot infections earlier, allowing improved treatment for patients as well as reducing unnecessary use of antibiotics. The technology could also reduce the length of hospital stays.

The path to approval will be supported by the University of Graz's Diagnostic and Research Centre for Molecular Biomedicine and Institute of Health Care Engineering with European Testing Centre of Medical Devices. These Austrian institutions have the credentials to support market authorisation of this new diagnostic under new EU regulations that come into force in May.

This will make commercialisation of the test possible in the European single market and many other developing and emerging markets that use CE-mark confirmation as a reference.

bit.ly/3EO9V3k

RADIATION THERAPY

'REVOLUTIONARY' PANCREATIC CANCER DEVICE

The first UK pancreatic cancer patients have been treated using a 'revolutionary"' device that allows them to receive radiotherapy during surgery, in the hope of boosting survival rates.

Nineteen patients at University Hospital Southampton (UHS) have received a full dose of radiotherapy in the space of a few minutes during their operations using the equipment, called Mobetron, which is funded by PLANETS cancer charity.

It is the first mobile, self-shielded electron-beam linear accelerator machine that delivers intraoperative radiation therapy to patients during surgery.

Arjun Takhar, UHS surgeon and member of the PLANETS surgical team, said: "This is an important development for pancreatic cancer patients for whom survival rates are still poor as it demonstrates change is possible and is coming."

bit.ly/3wiVv8I

IMAGES: VAYUCLEAR / ALAMY

IPEM 2025

Our strategic direction

IPEM Chief Executive Phil Morgan explains why it is important for the institute to grow and transform the way in which it works.

Professions and their institutions are part of our social fabric. The knowledge, skills and experience carried by professionals is maintained for the benefit of the community, and being a professional in any context is an earned privilege. For IPEM members this is more than a passing thought – it is something you live. Our members are dedicated, as is IPEM itself, to improving health through physics and engineering.

The benefits of your professionalism are shared by users of our NHS and in many other vital settings. We are the home of medical physicists, biomedical engineers and clinical technologists working in hospitals, academia and industry around the world. We offer a great range of resources, a ready-made network of like-minded professionals, and a platform for scientific leadership through which we are working to shape the future operating environment for our members. The challenge for volunteers and the staff team is to maximise IPEM's impact.

This summer we published our strategy - IPEM 2025 - which has two driving motivations. Firstly, it must enable the organisation to perform to its potential. To do this, we need to simplify IPEM's range of activities, focusing on what really matters: working in the public interest to support and maintain standards and practice development. IPEM 2025 will guide how we allocate our resources, bring together the charitable, professional, learned society and commercial elements of the organisation, and align the efforts of both staff and volunteers. That is why it has three straightforward core elements – professional development, community, and leadership – focusing on what we can offer our members and how we can serve the public.

The second motivation is risk. In recent years, 50% to 60% of IPEM's income has come from our journals, published through Institute of Physics Publishing and Elsevier, meaning we are dependent on them to support our other activities. Changes in publishing make it likely that the earning potential of journals will weaken over the coming decade. IPEM needs to boost income from membership, training and events to achieve long-term sustainability. For example, in 2019, 17% of our income came through membership subscriptions. In other professional bodies, this proportion is typically 40% to 50%. Our scientific meetings earned around 14% of our income; this needs to rise over the next few years to 20% to 25%. To achieve this, we need to grow and to transform how we work. This will not happen overnight, or even next year, but we are working towards it from here on.

If we embrace and demonstrate leadership, we will generate growth. I have added capacity to our communications team to improve our profile and created a new professional knowledge capability. We want to grow membership through improved member experience and impactful marketing and have already put in place measures to better recruit and retain volunteers. We will publish a further strategy, intended to shape debate about the future of healthcare science, in the next six months. In early 2022, a new website will vastly improve our digital presence, and further changes are planned to keep the organisation agile, responsive and increasingly effective.

To do all this and more we need you. Please volunteer and help us achieve that impact by developing our professionals, improving healthcare, and transforming lives together.

For more information, visit ipem.ac.uk/About-IPEM/IPEM-2025

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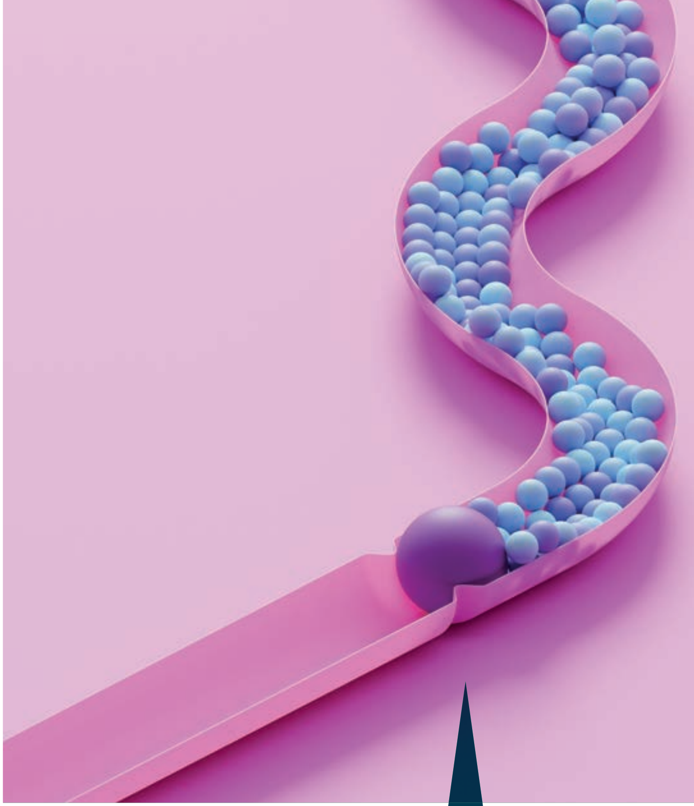
STRATEGY UPDATE

EXTERNAL RELATIONS MANAGER

Catch up with cancer

Sean Edmunds, the Institute's External Relations Manager, outlines the latest policy news and Institute updates.



How cancer services continue to be affected by the COVID-19 pandemic was the subject of several consultations which IPEM members contributed to this year.

These built on a special Cancer Summit, which was held in April and which IPEM attended, to make recommendations to the Government on how to tackle the COVID-induced cancer backlog.

The report, *Catch Up With Cancer - The Way Ahead*, was drafted following an inquiry launched by the All-Party Parliamentary Groups for Radiotherapy (APPGRT), Health and Cancer, who came together to launch the consultation "Solutions to the COVID-induced cancer backlog".

IPEM's Radiotherapy Professional Standards Panel (RTPSP) produced a detailed and comprehensive response to this, which was discussed in depth with parliamentarians, including Tim Farron MP, Chair of the APPGRT, Vice-Chair Grahame Morris MP, and Professor Pat Price, the Chair of Action Radiotherapy.

The APPGRT subsequently revised the report towards the end of the summer and once again sought input from IPEM.

Nicky Whilde, the new Chair of the RTPSP, led on updating the response to the report, along with other members of the panel, and

> The summit made recommendations on tackling the COVID-induced cancer backlog

STATUTORY REGISTRATION OF CLINICAL TECHNOLOGISTS

Efforts to move towards clinical technologists becoming registered professionals to help deliver better patient outcomes have been stepped up, led by IPEM.

The demands placed on the UK's health infrastructure by the COVID-19 crisis provided renewed impetus for IPEM to make the case for statutory registration of clinical technologists.

During the course of this year, IPEM pulled together a group of like-minded organisations to agree on the next steps. The group includes the Register of Clinical Technologists, the British Nuclear Medicine Society, the Institute of Healthcare Engineering and Estate Management, the Association of Renal Technologists, the Registration Council for Clinical Physiologists, the Academy for Healthcare Science, the British Society of Echocardiography, and the British Medical Ultrasound Society.

This group met throughout the year to agree on terms of reference and drew up a position statement.

In addition, questions on the issue were asked in parliament, and IPEM also organised and facilitated a roundtable podcast on the Health and Social Care White Paper, which saw the matter raised with panellists, including Angela Douglas MBE, Deputy Chief Scientific Officer for NHS England.

An experienced public affairs consultancy agency was engaged and helped to identify a range of key stakeholders, including MPs, peers, civil servants and health professionals who have been approached to try and ascertain their views on the current situation and the likelihood of achieving statutory registration for clinical technologists, which is still a priority for IPEM.

Professor Andrew Reilly, Director of the Science, Research and Innovation Council, also provided input.

This revised report was also submitted as evidence from IPEM to the House of Commons Health and Social Care Committee inquiry on how to improve cancer services in England. This inquiry was held to look in more detail at the reasons why the proportion of people surviving cancer for longer is lower in England and to look at ways to improve it. The Committee will publish its report in due course.

The final area on this subject, which IPEM also supported, was a workforce survey by the APPGRT, in conjunction with Action Radiotherapy, to seek views on improving cancer services and clearing the COVID-19 cancer backlog.

Away from matters concerning the impact COVID-19 has had on cancer services, IPEM responded to a consultation by NHS England and NHS Improvement on a race equality strategy.

The aim of the strategy is to establish standards for advancing race equality, eliminating discrimination and fostering good relations in the NHS. Eva McClean, IPEM's Equality, Diversity and Inclusion Manager, completed the survey response to this consultation.

In the autumn, IPEM contributed to a joint letter organised by the Science Council to Chancellor of the Exchequer Rishi Sunak, regarding the Government Spending Review.

IPEM was one of 26 professional bodies that signed the letter, which called on the Chancellor to ensure consistent year-on-year rises in science funding, remedy cuts to science programmes, and secure further investment in science education.

The Institute ensured there were references made within the letter to the vital role played by healthcare scientists, clinical engineers and technologists in the response to COVID-19.

IPEM also signed a letter from the Royal Academy of Engineering, along with more than 30 other leading scientific organisations, to the Chancellor calling for him to deliver on his promise to invest £22bn in research and development by 2024/25.

You can read both letters on the website at **ipem.ac.uk/News-External-Affairs/Latest-News**

IMAGE: GETTY

THE BIG DEBATE

Sustainability in healthcare and science

Hot on the heels of the COP26 UN Climate Change Conference, we ask three IPEM members what action is needed in their sectors.

Q *The NHS is responsible for 5% of the UK's carbon footprint. Has the NHS been too slow to act on the climate health emergency?*

DR ROBERT CHUTER

While it is excellent that the NHS has committed to be net zero by 2040, I think that it – along with everyone else – has been too slow to act. If we had started reducing our global carbon footprint in 2000, we would only have needed to reduce it by 4% a year to stay below 1.5°C of warming (which is what is considered safe by climate scientists); now it is nearer 20% a year to achieve that goal. Having wasted so much time, we now find ourselves having to make much bigger and more difficult changes. And the longer we wait, the worse it will get.

LAURA PERRY

Arguably we've all been too slow to acknowledge, plan and execute the changes required due to the climate emergency. The negative impact of climate change on health through air pollution, heatwaves, flooding, increased spread of infectious diseases, reduced access to clean water and food-chain disruption is no longer debatable. The NHS is the world's first national health system to commit to becoming 'carbon net zero' to help tackle the climate and health emergency. This is something we should all be proud of. Now let's make it happen!

DR NATHAN DICKINSON

Much of society was – and in many ways still is – slow to understand the real significance of climate change and act meaningfully. The initial reaction of the NHS reflects this wider problem. However, the development in our understanding of the climate emergency and its numerous healthcare implications is accelerating the pace of action on these issues. Focusing on positively moving forwards, understanding that the reduction in emissions required to mitigate the worst climate change outcomes becomes very much more challenging the longer we delay, will be more impactful than worrying about the past.

Q Simon Stevens announced a route map to make the NHS the first 'net zero' health service. Is that realistic?

ROBERT

I think it is doable but it is impossible without proper investment. The NHS is – like most public services – struggling after a decade of austerity, so to ask it to also make huge reductions in its carbon footprint is maybe asking too much. The only way to make it work is to invest in the NHS and embed environmental sustainability into everything we do, from staff training and staff travel to sustainable building practices. We also need to invest in preventative medicine, as stopping someone getting ill in the first place has a much lower carbon footprint than treating it – for example improving diet and exercise to stop heart disease. Net zero by 2040 is a very ambitious goal but the impact of not moving to net zero quickly would be even more detrimental to people's health.

LAURA

The *Delivering a net-zero NHS* document was developed collaboratively and clearly highlights the part each NHS worker and patient has to play. I found the document rather inspiring! The review of NHS emissions appears comprehensive. The plan includes quantitative analysis of reduction in NHS emissions achieved to date and required in future. Route maps are included that match the emissions required to different projects and changes, giving the contribution of each together with examples where they have already been tested. This gives confidence that wider implementation and resultant reduction in emissions can be achieved. But it needs proactive engagement from trusts

> **"THE ONLY WAY TO MAKE IT WORK IS TO EMBED SUSTAINABILITY INTO EVERYTHING WE DO**

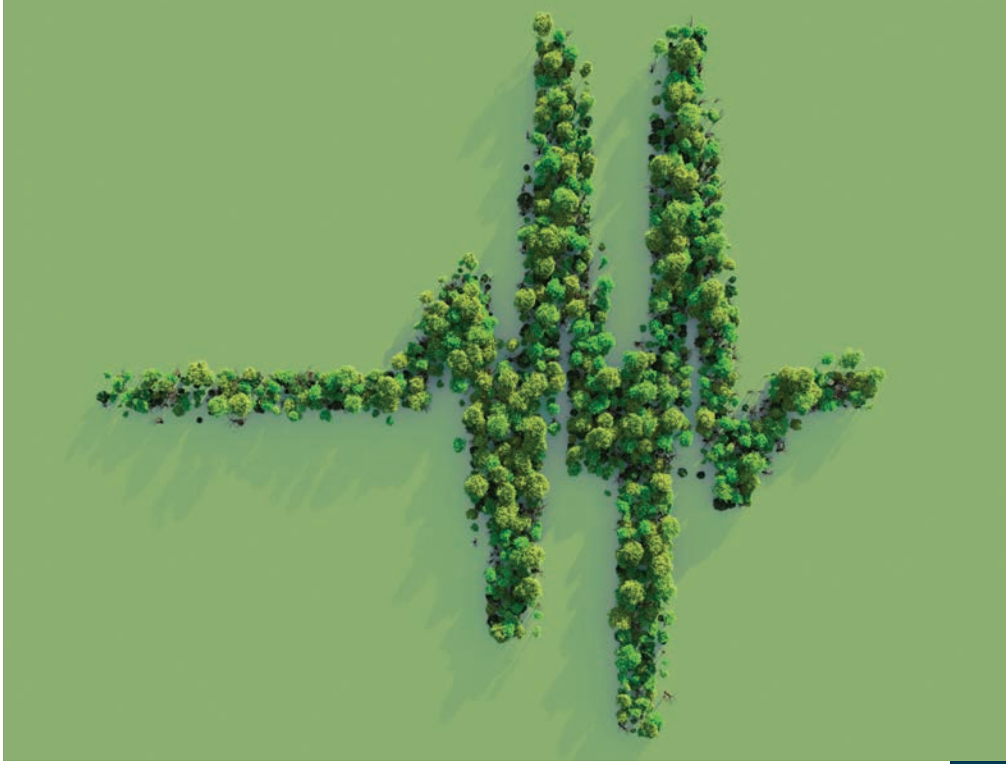
MEET THE EXPERTS

DR ROBERT CHUTER
Principal Clinical Scientist in Radiotherapy and Chair of the IPEM Environmental Sustainability Group
The Christie NHS Foundation Trust

LAURA PERRY
Principal Nuclear Medicine Physicist and Co-chair of the Imaging Environmental Sustainability Group
Imperial College Healthcare NHS Trust

DR NATHAN DICKINSON
Principal Clinical Scientist, Medical Physics and Clinical Engineering
Nottingham University Hospitals

IMAGES: GETTY / SCIENCEPHOTO



and hospitals, which will be the challenge in an already stretched service. In my experience, there is plenty of enthusiasm and energy among staff to make important changes happen.

NATHAN

Becoming a net zero service is achievable, but it is a significant challenge. Multiple reports demonstrate that historical workforce planning and resultant staffing levels have left services struggling to cope today. The additional work associated with making the NHS a net zero organisation in future therefore needs to be properly analysed and resourced for it to happen. It is worth being mindful of a wider view of the ecological emergency – there are other greenhouse gases more damaging than carbon dioxide, environmental pollution is causing adverse health outcomes, and reductions in biodiversity will impact food production and health. These things can be missed through being extremely focused on net zero carbon, even though that is very important.

Q What technologies can be utilised in hospitals to make them greener?

ROBERT

A basic tenet of sustainability is to reuse and mend what you already have rather than to buy new technology. However, a good place to start would be to install solar panels on the roofs and improve the insulation of NHS buildings.

LAURA

There are so many options already available to us and the exciting thing is that most save money and carbon emissions while also improving our patient service! Within hospital estates, LED lighting and on-site renewable energy and heat generation can be utilised – within my trust, an air source heat pump and solar panels are being installed. Web and telephone-based consultation and meeting technology, together with working from home options, are reducing travel and journeys. Improved availability and affordability of electric vehicles will help reduce the impact of the remaining journeys. In my department we moved to video consultation with patients before I-131 hyperthyroidism treatment, replacing an in-person clinic where possible. In addition to reducing patient travel and associated emissions we have also improved convenience and accessibility of the clinic for our patients.

NATHAN

It's not high-tech, but basic upgrades to the NHS estate, which in places is in poor condition, are needed. Building insulation, draught-proofing, double glazing, solar panels and LED lighting have been available for some time now. Once the basics are in place looking at modern heating systems and so on is warranted. Electrification of NHS vehicles would be really positive, and switching to a green electricity supplier is an easy, impactful win. Sometimes going low tech is good too – some trusts are using cycle couriers rather than driving things across sites.

Q What kind of projects is your section/ area undertaking in terms of sustainability?

ROBERT

We recently received funding from the North West Greener NHS Innovation Fund to estimate the carbon footprint of the radiotherapy pathway. This will start at The Christie but we hope to win further funding to include other small, medium and large radiotherapy centres. The IPEM environmental sustainability group (ESG) is also developing plans to expand this to nuclear medicine and brachytherapy.

Other projects that the ESG are involved in include:

- Connecting with procurement to change from disposable cups and cutlery to vegware cutlery in the canteen
- Setting up a 'Green Ambassadors' scheme, to get one member of staff in each area to lead the discussion about sustainability with colleagues, and help implement changes
- Awareness-raising - insertions into all-staff emails, talks to staff groups, blogs, articles and so on
- Writing a letter to manufacturers of radiopharmaceuticals starting a discussion on the need to reduce waste and packaging.

LAURA
As co-chair of my trust's Imaging Environmental Sustainability Group I have been supporting group members to lead on changes they are passionate about. Pilot projects are running into use of reusable sterile gowns in interventional radiology and automatic 'sleep' for some PCs between 6pm and 8am. We have also looked at waste streams: expanding recycling of CT contrast to all trust sites and working to segregate waste appropriately leading to a reduction in both cost and associated emissions of our waste management.

NATHAN
Our medical physics and clinical engineering environmental sustainability group is working on reducing waste production, expanding recycling facilities, and reducing 'wasted' electricity consumption. Many of the big changes we'd like to see are not under our local control and are being planned outside our departments. We're therefore actively talking to others in the trust about approaches to transport, heating, waste management and the future development of the estate to understand what is planned and draw attention to our concerns.

Q What direction do you see medical physics and clinical and biomedical engineering taking around sustainability?

ROBERT
As scientists we are well placed to understand how serious the climate emergency is. More importantly, our analytical skills and attention to detail will be invaluable in helping our departments determine and reduce carbon footprint hotspots.

LAURA
Within imaging it will be important to calculate the carbon footprint of modalities and studies to help us identify priority areas for improvement. In the future, this data could contribute to decision-making, together with effective dose calculations, enabling referrers and patients to choose low-carbon and low-dose options where clinically equivalent – analogous to Asthma Patient Decision Aids for low-carbon inhalers.

NATHAN
Having an analytical, problem-solving mindset, I think our professions are well placed to consider issues such as the carbon footprint of clinical procedures and provide a more nuanced understanding of the real environmental costs of what we do. Where options are presented with equivalent clinical outcomes, this information would be really useful to make sure the solutions implemented are as sustainable as possible. The development of and adoption of novel technologies (such as units that destroy nitrous oxide exhaled by patients using Entonox during childbirth) is another obvious area where we can have an impact.

Q What could the environmental legacy of the pandemic be in relation to UK health services?

ROBERT
In radiotherapy it is possible that the pandemic has hastened the move to stereotactic ablative body radiotherapy. By using fewer fractions with larger doses, our patients travel less and the linac is used less too. If clinical trials show that they are at least equivalent to standard dose fractionations, this could be a big carbon saver.

A lot of people rediscovered the joy of cycling, leading to an increase in people commuting via bike, which has well established health and environmental benefits. Lockdowns also reminded people of the health benefits of green space, which will hopefully make people more willing to protect it from development.

LAURA
The pandemic showed that the NHS has an impressive capacity to adapt and respond in an emergency, and governments are able to find funding when required. The roll-out of digital care was accelerated and the reduction in costs and environmental impact with improved patient service is a great achievement. Conversely there has also been an increase in single use PPE, plastics and cleaning products.

The pandemic has reinforced the connection between public health and the NHS and this legacy is reflected in the NHS's plan to improve population health through and as part of the plan to achieve net zero.

NATHAN
Immediate benefits that spring to mind are remote and community access to services, as well as remote working for staff. However, remote access is not suitable for all patients, and digital solutions have their own carbon footprint. A robust analysis of this is needed to understand the real impact across the whole system.

There has been a significant increase in single-use plastic. Some trusts are trying to address this by rolling out reusable PPE or recycling surgical masks, but this isn't widespread. Development and wider adoption of such practices is required.

The positive legacy I see from the pandemic is how quickly almost every aspect of the NHS changed when it really had to. Before the pandemic, the scale of change required to improve the environmental sustainability of the NHS seemed too large and difficult to achieve. I think this view has diminished significantly, which leaves me feeling optimistic.

PREGNANCY AND ARTIFICIAL INTELLIGENCE

Ejay Nsugbe and **Dawn Adams** on harnessing the power of prediction machines for proactive care of preterm mothers within pregnancy medicine.

Preterm births have been identified by the World Health Organization (WHO) as a global epidemic and are the most common cause of death in infants under the age of five after pneumonia. In addition, survivors often need to deal with lifelong illnesses that span the respiratory and neurological.

Being an epidemic of sorts, the implications of preterm births affect not only health but also financial aspects, from the care for both the mother and the survivors. In spite of the apparent implications of the preterm epidemic, effective care means continue to be lacking, the majority of which are reactive and do not offer any ability to forecast a potential preterm birth prior to its occurrence. This article explores how the prospect of machine learning and prediction machines can be applied as a clinical decision support tool towards the prediction of preterm and thereby serve as a means of enhancing care strategies for pregnant patients.

> "SINGLE BIOMARKERS ARE LARGELY INEFFECTIVE IN THE DIAGNOSIS OF THE PRETERM BIRTH EPIDEMIC

Human gestation and preterm

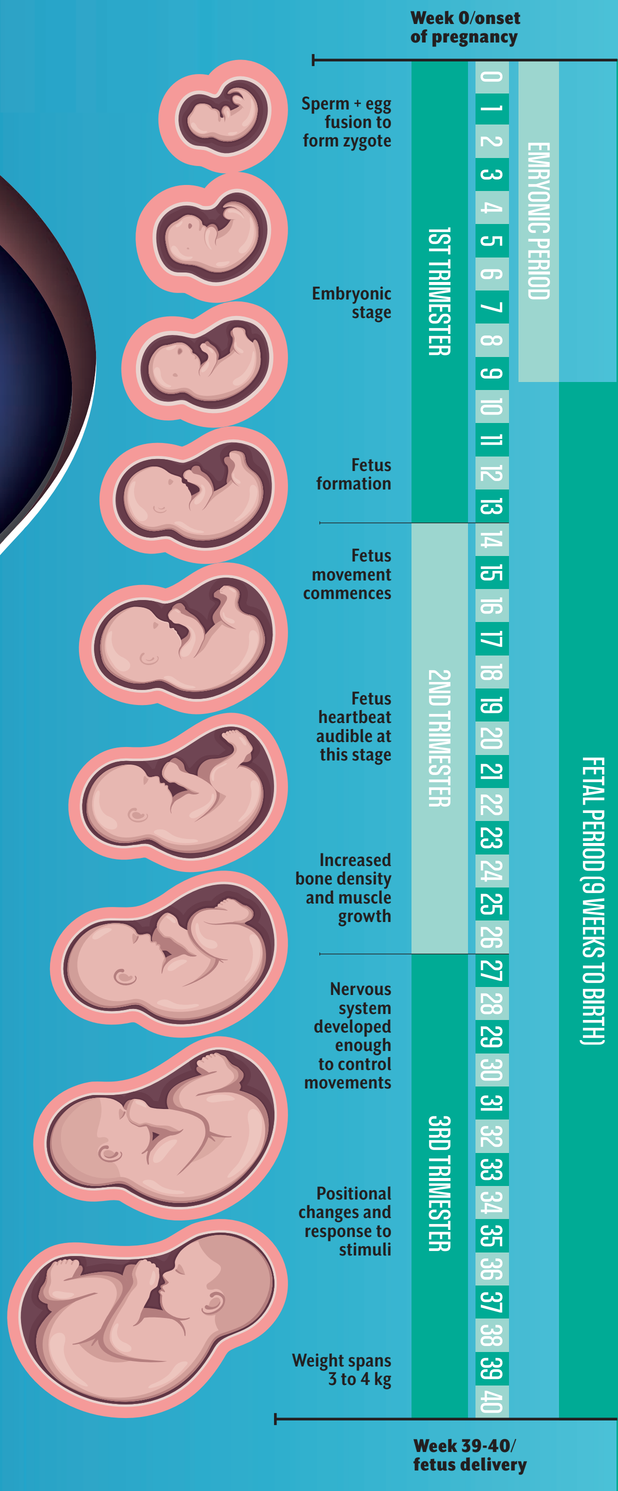
Human gestation can be divided into three phases known as trimesters. As part of the first trimester, bodily changes begin to manifest themselves in the mother due to nurturing a fetus, while the brain and genitalia of the fetus begin to develop – this phase is when the majority of miscarriages occur.

During the second phase, the fetus can grow up to five inches, it begins to exhibit dynamic motion, and it also develops a circadian rhythm of sorts. At this stage, the sex of the fetus can be determined via the use of an appropriate imaging tool.

By the third trimester, the fetus can be felt to be proactive within the womb, with more movements and a response to external stimuli to a degree, i.e. light.

IMAGES: GETTY / SCIENCEPHOTO

Figure 1 Timeline of gestation phases



A visual timeline of the various gestation phases can be seen in Figure ❶.

Preterm can be defined as the process of giving birth prior to 37 weeks of gestation. As mentioned, preterm is one of the most common causes of death in children under the age of five. In addition to this, newborns who have been delivered preterm are more susceptible to dying and can be more prone to neonatal infections. Preterm births also carry financial and economic implications: in England and Wales, the cumulative cost of care for preterm children from birth to adulthood is £3bn, and is further broken down into £62,000 for a moderate preterm and £95,000 for an extreme preterm case.

Due to the inaccuracies of current preterm prediction methods, the cost of a false positive and subsequent hospitalisation is said to be approximately £15,000 per patient, while public health studies done by van Baaren et al in the Netherlands showed that for the annual delivery rate within the country, an effective preterm prediction method could lead to annual savings in the range of €2m to €14m per year.

Ethnicity also plays a key role in preterm, largely due to obstetric outcomes notably varying across ethnic groups, where it has been noted that those with black ethnicity have a shorter gestation length (largely attributed to ethnic history and socioeconomic factors), with the maternal ethnicity playing the key influencing factor. This makes apparent the need to factor in ethnic differences when providing care to pregnant patients as part of strides towards delivering precision-based care.

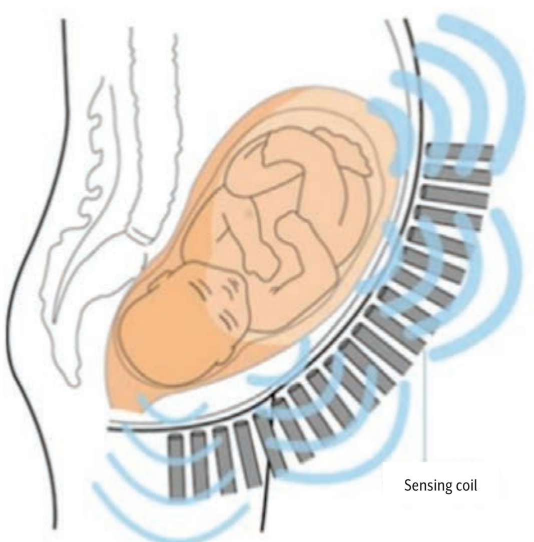
Diagnosing potential preterm

The top ranked countries where preterm occurs include India, China, Nigeria, Pakistan, Indonesia, the US, Bangladesh, the Philippines, Democratic Republic of Congo and Brazil, of which the cumulative sum from these 10 countries accounts for 60% of all the preterm births worldwide.

This follows on into neonatal care, where in high-income countries 66% of babies born extreme preterm survived, in contrast with low-income countries where only 30% survived. This shows that in addition to tackling the preterm epidemic, adequate antenatal care is also required.

The current predominant means of diagnosing potential preterm births includes the measurement of the cervical length, which has been linked to shorter gestational lengths, where the shorter the cervix suggests a greater risk. Biochemical markers have also been utilised, where fluidic emissions such as urine, amniotic fluids and cervical mucus have been analysed for indication of a potential early birth; and the uterine contraction frequency is a means also employed, where instrumentation such as the electrohysterogram (EHG) and tocogram are utilised for this purpose. These methods have been shown to carry limitations, which have led to unreliable prediction of preterm births.

Figure ❷ Illustration of the MMG instrumentation acquiring uterine contraction signals from a pregnant patient



With preterm being a multifactorial problem, it has been acknowledged that single biomarkers are largely ineffective in the diagnosis of the epidemic. Thus, of late, the emphasis has been placed on the study of the contraction pattern of the uterine wall (womb) as a means of inferring early deliveries.

During the third and final trimester, these contractions intensify until the birth of the fetus, where the contraction of the uterine wall involves cellular depolarisation and associated generation of a bioelectrical signal, as with any other anatomical tissue. As these bioelectrical contraction signals are a function of a number of physiological factors, they have been seen to encode information that can be used to predict the scenario of a preterm birth, with the appropriate utilisation of physiological instrumentation and appropriate signal processing methods.

"THE FRAMEWORK'S ANALOGUE IS A SET OF UTERINE CONTRACTION SIGNALS, WHICH PREDICTS THE IMMINENCE OF LABOUR

Role of AI

The literature has shown a host of positive results in the recognition of patterns from uterine contraction signals using machine learning models, thus leading to the impression that this could form part of an artificial intelligence (AI)-driven clinical decision support interface that facilitates human-machine interaction for enhanced care for preterm patients. This has been the emphasis of publications in this area by Nsugbe et al, where the framework has been implemented using the principles of cybernetics, and hosts a prediction machine whose analogue is a set of uterine contraction signals, and predicts the imminence of labour and preterm. This prediction is ultimately passed on to the clinicians who review the supporting information prior to deciding on a follow-up course of action. This minimises preterm deliveries, and effective care allocations in the face of an extreme preterm case. These studies utilised EHGs and magnetomyograms (MMGs) as a means of monitoring the uterine contractions, where a range of positive results were obtained for various prediction case studies investigated.

The study involving the MMG instrumentation also investigated the influence of ethnicity on the prediction of pregnancy labour, where it was seen that a patient's ethnicity could be differentiated solely based on acquired MMG uterine contraction signals. It was also seen that having taking ethnicity as *a priori*, an "ethnic-specific" prediction machine made for an enhanced prediction of labour imminency. An illustration of the MMG instrumentation recording uterine contraction signals can be seen in Figure 2.

Conclusions and limitations

AI methods have been seen to form data-driven means of decoding uterine contractions, which can be used to predict labour imminency and preterm births. This, alongside the knowledge of clinical experts, has been coupled in a cybernetic system poised towards enhancing care strategies for potential preterm patients, where the inclusion of the AI-driven prediction machine can contribute towards the minimisation of misdiagnosis and subjectivity within aspects of pregnancy medicine.

In addition to this, benefits of the proposed framework include a projected reduction in the overall rate of preterm within a clinic, greater survival of extreme preterm newborns due to proactive care, and an anticipated reduction in the psychological trauma sustained by the delivering mothers.

The limitations associated with this work include the constrained sample size used for the design of the AI-driven prediction machine (in the region of 20 patients), which would need to be greatly expanded upon and made more robust as part of future work. Due to anticipated deployment in clinical settings, model explainability is set to be of paramount importance – thus it is essential for black-box models to be avoided in order to boost the potential of gaining clinical approval.

The proposed framework is expected to be universally implementable by clinics globally; thus prototype-based implementation of the system would need to be parsimonious and computationally efficient in order to keep the hardware demands at a minimum. This would form a core aspect of further work in this area which would include clinical validation of the designed clinical framework. ○

Ejay Nsugbe *runs Nsugbe Research Labs, Swindon, and* **Dawn Adams** *works in computer science and informatics at Ulster University. The author would like to thank Brian Kerr from Kerr Editing for proofreading the manuscript. The author would also like to acknowledge the selfless contributions of the following researchers towards the project: Oluwarotimi Samuel, Olusayo Obajemu, Ibrahim Sanusi and Michael Provost. References were supplied and can be requested by emailing rob.dabrowski@redactive.co.uk*

REDUCING DOWNTIME

Danielle Watson, an Apprentice Radiotherapy Engineer, outlines a project to improve efficiency.

The Primary Collimator Breakout Box is aimed at aiding fault diagnosis in the primary collimator and secondary filter of Elekta linacs. The box allows the user to see switch signals from the collimator assembly without removing the Beam Limiting Device (BLD). Providing a non-invasive diagnostic tool with the aim of reducing downtime and eliminating the need for a head lift and the post-repair physics quality assurance.

The need for the device arose following an intermittent primary collimator fault at another site. The fault was gantry angle specific; however, to remove the BLD the gantry must be at 180˚, therefore not allowing the mechanism to be observed in a fault state. Without the breakout box, the fault could only be investigated by removing the BLD and observing the primary collimator movement, which is a lengthy process causing a large amount of machine downtime.

Developing Mk1

The design for Mk1 was proposed by an Elekta engineer and its parts funded by Elekta. My role was designing the project and building the device. The design was built on Veroboard, making it easy to adjust and adapt. Comparator chips detected when each signal was HIGH, lighting the LEDs. A risk assessment was conducted, considering the mechanical, electrical and manual handling hazards. Mk1 was tested using replicated signals before being tested on a working machine. Once the box was in use, training and documentation was provided to staff to enable them to use it safely. Though effective, Mk1 did have some areas that could be improved, providing motivation for a second design.

Making improvements with Mk2

To resolve these issues and make the device easier to use, Mk2 was proposed. The design would detect the status of the four microswitches and display the decimal value onto two seven-segment displays. The initial ideas were discussed with Elekta, which suggested using field-programmable gate arrays (FPGAs) due to their low cost, versatility and future-proofing. With the ability to monitor multiple signals at once, a much higher sampling rate could be achieved than that of a microcontroller. This also provided an area for personal development, as I had not used FPGAs before, but would be using them later in my degree course.

The project began by using research and test code to become familiar with FPGA language structure and commands. Then the initial code was written, testing the result using microswitches on Veroboard. Mk2 used the same principle as Mk1, tapping into the linac voltages, and using the linac supply to power the box. The FPGA operates at a 3.3V logic level so Zener diodes reduced the signals to the appropriate logic levels and a

Figure ❶ Reduction in downtime using breakout box

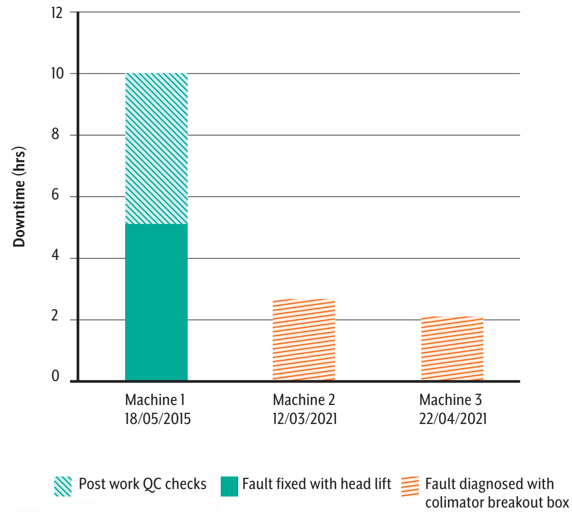


Figure ❷ MkI breakout box

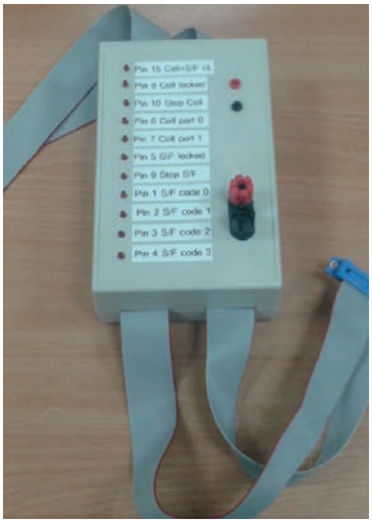


Figure ❸ Mk2 breakout box

" THIS NON-INVASIVE TOOL WAS AIMED AT REDUCING DOWNTIME

regulator lowered the power supply to 3.3V.

The circuit was built on Veroboard and terminal points added so that the box could be disconnected for maintenance or repair. The circuit was then fitted into a bespoke case, which I designed in CAD software and 3D printed.

After thorough testing and reviewing the risk assessment, Mk2 was tested on a working linac. During testing, the primary collimator on the linac seized between the two ports, due to one port not being used clinically. This highlighted a risk that had not been considered during the project. Fortunately, the bearing was accessed through the service hatch and lubricated to regain movements. On reflection, this could have been avoided by regularly rotating the primary collimator and illustrates a use of the breakout box in preventative maintenance. The motor current can be recorded at regular intervals to quickly identify any bearing degradation and highlight when additional lubrication or repair may be required.

Displaying the secondary filter position on the box allows engineers to quickly check if the filter is in the correct position. Using an FPGA also allowed me to invert the signals with negative logic, configuring the LEDs so that they turn off when they are in the correct state to beam on. This allows engineers to quickly identify which switch may be at fault.

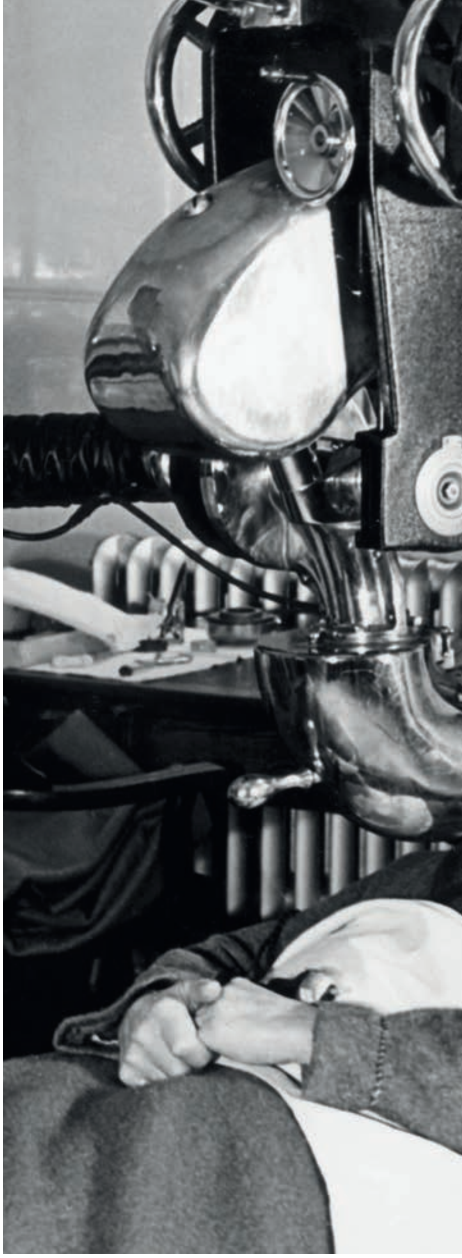
Since Mk1 was completed, it has been used in three faults, once at an external radiotherapy department and twice at The Christie. Figure ❶ shows the vast reduction in downtime. Without the breakout box, the fault on Machine 1 required a head lift to diagnose the fault and adjust the microswitch position. A head lift is a lengthy procedure that also incurs multiple risks. A large amount of post-work physics quality control must be completed to ensure that the beam has not been affected during the repair. This resulted in a downtime of 10 hours. On Machines 2 and 3, the breakout box was used to correctly identify the switch at fault and adjust/replace the switch. The switches were accessed through the service hatch, removing the need for the head lift, and reducing the downtime to two hours.

Conclusion

The project has been hugely successful in reducing downtime and has been personally rewarding. Mk2 has made the breakout box easier to use; however, improvements could still be made. I hope to further develop the project, building a Mk3, with the aim of making the device as easy to use as possible. ◘

THANKS

Danielle Watson is Apprentice Radiotherapy Engineer at The Christie, Manchester. She would like to thank Elekta's **Jeno Felhosi** for inspiring this project and for guidance, encouragement and advice.



AGENT OF CHANGE

How the Radium Commission created hospital physics

Francis Duck on how physics departments became established in hospitals outside London during the 1930s and the role the Radium Commission played.

RADIUM

REQUIREMENT F

"A Physics Department is needed, not only to undertake independent research, but to work out plans for the dosage etc of special cases and to assist the medical staff in other problems arising in the course of the work. Moreover, every Institution using radium should have at its disposal expert advice on (i) the safe custody of radium, (ii) the protection of personnel and (iii) the tracing and recovery of radium fractions inadvertently lost or burnt." Radium Commission, 1929.

The Committee of Civil Research was established in June 1925 with the purpose of bringing expert scientific advice to the stagnant economy of post-war Britain. In July 1928, a subcommittee was set up, under the chairmanship of the 4th Lord Rayleigh, to examine the radium requirements of the country.

By that time the Government had already distributed 2.4 g radium for medical use to various centres, mostly in London. This had been recovered from luminous displays of military vehicles and aircraft after WWI, and remounted in needles and plaques suitable for medical use. A small proportion of this stock had been distributed outside London: 147 mg to Birmingham, 115 mg to Cardiff, 96 mg to Aberdeen and 221 mg to Dublin. By 1929, there was also about 20 g more in medical use, as a result of donations and hospital purchases. The largest stock of privately acquired radium, 1.48 g, was in Manchester, and the 17 centres recorded to be using radium included, surprisingly, Margate and Newton Abbot.

In its first report in March 1929 this Radium Subcommittee proposed the establishment of a central stock of radium for medical purposes, to create some order to "the fortuitous geographical distribution" that had arisen because "institutions acquire as much or as little as the resources at their disposal or local munificence render possible".

National radium centres were to be established to manage and coordinate radium therapy locally, to which radium would be loaned

❶ Radium treatment in a London hospital, England, 1940, A patient is prepared for radium treatment by a female doctor and nurse at a London hospital in 1940.

IMAGE: GETTY

"THIRTEEN NATIONAL RADIUM CENTRES WERE ESTABLISHED, EACH NOMINATED BY THE LOCAL MEDICAL FACULTY

subject to central inspection against stated operational requirements. See box for Requirement F from the report (left).

The need for a physicist's support was not self-evident to most radium therapists. After all, radium had already been in medical use for a quarter of a century, largely without their direct involvement. This official statement established a different view.

A National Radium Trust, chaired by a senior politician, was set up to manage the purchase of radium for the central stock. In turn, the Trustees set up the Radium Commission, whose role was to manage the custody, distribution and use of the radium. The Middlesex Hospital physicist Sidney Russ, appointed by the Medical Research Council, became the influential scientific secretary of the Radium Commission, a role he played until August 1935. It was immediately recommended that an additional 20 g radium should be purchased. Rules for the "Care and Custody of Radium" were set out, largely based on those in force at St Bartholomew's Hospital, The Middlesex Hospital and The Cancer Hospital in London. These included design instructions for a radium bench and safe (Figure ❶).

National and regional radium centres

Thirteen national radium centres were initially established, each being nominated by the medical faculty of the local university. There were four in Scotland, one in Wales and seven in England. A further national centre and postgraduate school was established in London, combining Mount Vernon Hospital and the Radium Institute.

The geographical distribution left some areas, notably East Anglia and the South West, poorly provisioned. This led to the establishment of further regional radium centres, for example in Norwich and Plymouth. The sixth annual report (1934-1935) included a map showing the location of all the centres including, in addition, four recognised hospitals, treating with radium but having none on loan yet from the Commission (Figure ❷).

Success and failure

It soon became clear to the commission's inspectors that some centres were aligned

Figure ❶ Design for a radium bench. Radium Commission 3rd Annual Report 1931-1932.

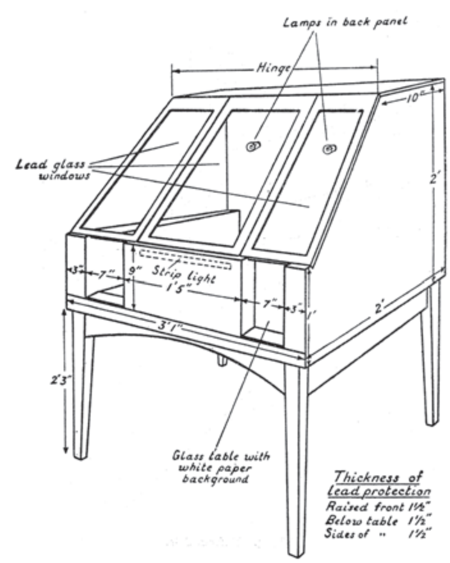
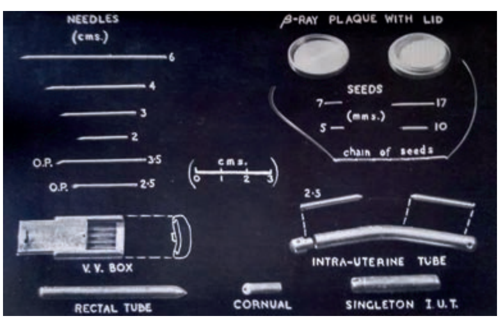


Figure ❷ Map showing the locations of national and regional radium centres, 1935.

Figure ❸ Sources for radon therapy. Jennings WA, Russ S. Radon: Its Technique and Use, 1947.



"BY 1936 IT WAS CLEAR THAT THE NEED FOR MORE RADIUM EXCEEDED THE ANNUAL TRUST BUDGET

with their expectations, and some were not. The Holt Institute and Christie Hospital at Manchester, where there had been a Radium Institute since 1915, was singled out for special praise and, as early as 1932, identified as being "experienced and progressive" and, later, as the most adequately staffed in the country and indeed in Europe. Sheffield was applauded as having the best coordinated service, and the arrangements at Leeds were similarly admired. In Scotland, Aberdeen was excellent, having close links with the university physics department.

On the other hand, some centres failed to meet the Commission's requirements. By 1933, Dundee was closed as a national centre. 0.5 g radium, initially on loan to Bristol, was withdrawn by 1934, reinstated only when the Bristol hospitals agreed to co-operate with one another. There were similar local tensions in Liverpool, where, for a while, a parallel radium service operated away from the national centre. A compromise in Glasgow authorised three separate centres. Newcastle was hampered by lack of local funds. The regional centre designated for Nottingham was, by 1933, established at Lincoln. Pressure for improvement was applied even in London where, in 1932, the loan of 3 g radium to the Westminster Hospital was discontinued.

These local differences are reflected in the chronological order in which physicist appointments were made in the various centres (Table ❶). By 1936, physics departments had been set up in hospitals in Aberdeen, Birmingham, Manchester, Leeds and Edinburgh. The local skirmishes in Bristol, Liverpool and Glasgow delayed the appointments there but, by 1940, each had a hospital physicist in place. The regional centres at Stoke-on-Trent and Bradford had appointed physicists, trained in Manchester, by 1943. A physicist from Birmingham was working part-time at the Recognised Hospital at Wolverhampton by 1944. Nevertheless, in spite of the commission's recommendations, physics appointments were not made everywhere. For example, there was no physicist in Cardiff until 1944, when someone was appointed part-time from the university.

Radon therapy

The pressure to appoint a physicist arose also from the introduction of new techniques. The first British radon facility had been set up in Dublin by the physicist John Joly in about 1914. When the Radium Trust was established, it agreed to allocate a total of 3 g of its initial purchase of radium for the production of radon. This was done with the intention of decentralisation and to relieve pressure on radon production at the Radium Institute in London. By 1932 Birmingham and Aberdeen were in a position to accept their full 0.5 g allocation and, in due course, Liverpool, Manchester and Newcastle all established local radon production. The radon was encapsulated in plaques, tubes or needles, and used as a short-half-life equivalent for any radium therapy (Figure ❸). The specialised facility (Figure ❹) was typically set up in the local university physics department, but it served to confirm the importance of physics for radiation therapy, cement relationships between physicist and doctor, and create a more fertile environment in which hospital physics departments could become established.

External beam radium therapy

Radium was expensive, estimated in the first report as about £12,000 per gram, and UK sources were meagre. The Trust purchased 186.5 mg British radium extracted from Cornish ore, which was loaned to the NPL.

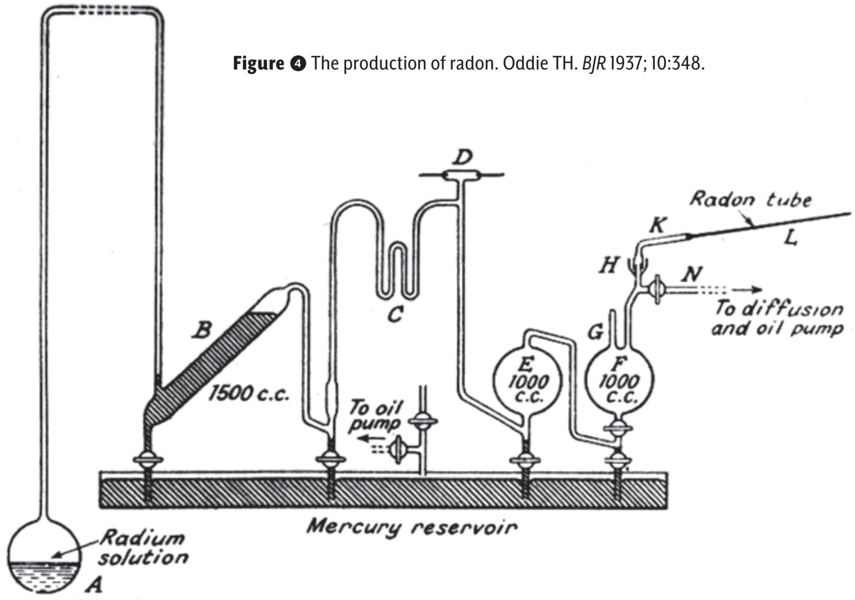


Figure ❹ The production of radon. Oddie TH. *BJR* 1937; 10:348.

Apart from this, the main supplier initially was the Belgian company Union Minière du Haut Katanga, which processed radium ore from the Belgian Congo. By 1936 it was becoming clear that the need for more radium exceeded the annual trust budget. That being so, the trust arranged with Eldorado Gold Mines of Canada for the loan of 20 g radium for a period of five years, with an option to buy.

Now well stocked, the Commission was in a position to offer significant amounts to centres to either set up or to add activity to a "radium bomb" or external therapy unit. During 1937 and 1938, loans of up to 5 g each were made to the three national centres in Scotland, Aberdeen, Glasgow and Edinburgh, three of the English national centres, Birmingham, Leeds and Sheffield, and the regional centre at Bradford. This significantly expanded external beam radium therapy throughout the country.

Additionally, the Manchester Radium Institute received 1.6 g for a radium collar. These investments added further local pressure to establish a physics department in those centres still lacking one, and for expansion in those that did.

1937: Endorsement of the hospital physicist

The eighth report of the Radium Commission, in July 1937, included a general survey of the "radiotherapeutic services of the country". Here we find much more robust statements on the need to employ physicists in hospitals. An efficient centre should "keep fully occupied at least one gramme of radium, possess an efficient deep X-ray therapy apparatus and employ at least one whole-time radiotherapist and a physicist". And again: "The services of a physicist with special experience in radium and X-rays must be available to the department and… it is desirable that a whole-time physicist should be attached to the department."

The creation of hospital physics

When the Radium Commission was formed in 1929, the only physicists employed by hospitals were in London: Russ at the Middlesex, Hopwood at Bart's and Mayneord at The Cancer Hospital. During the next decade, and under steady pressure from the Radium Commission, hospital boards outside London slowly recognised the importance of physics as an essential component in radiation therapy, and made their first physicist appointments. The Hospital Physicists' Association was formed in 1943 and, while London members still dominated, 28% of its 53 founders came from outside the metropolis. Hospital physics had become established nationally, and the vision of the Radium Commission had started to take effect. ◘

Francis Duck *is a retired medical physicist who has spent most of his career working in medical ultrasound. He would like to hear from anyone who has further local knowledge of the events outlined in this article. bathduckf@gmail.com*

Table ❶ First appointments of hospital physicists outside London.

City	Institute	Date	Physicist
Aberdeen*	University Radon Centre	1931	Harry Griffith
Birmingham*	General Hospital	1934	Francis Phillips
Manchester*	Holt Radium Institute	1934	Herbert Parker
Leeds*	General Infirmary	1935	Bill Spiers
Edinburgh*	Royal Infirmary	1936	Charles Murison
Liverpool*	Regional Radium Centre	1938	Thomas Chalmers
Bristol *	General Hospital	1939	John Munson
Glasgow*	Western Infirmary	1940	Walter McFarlane
Bradford+	Regional Radium Centre	1941	Elsie Algar
Guildford	Emergency R/T Centre	1941	Raymond Quick
Sheffield*	National Radiotherapy Centre	1942	Harold Miller
Stoke-on- Trent+	North Staffs Royal Infirmary	1943	Kenneth Tweedie

** National Radium Centres, + Regional Radium Centres*

GF
GENERAL FEATURES

RETHINKING MEDICAL IMAGING

How could new methods, technologies and work practices impact the post-pandemic backlog and patient outcomes? **Edward Peake** investigates.

In March 2020, shortly after the UK went into lockdown, Boris Johnson ordered the NHS to cancel all non-emergency treatment. Statistics for the following month showed diagnostic imaging was down 66% on the previous year across all modalities. The Royal College of Radiologists (RCR) and the British Institute of Radiology (BIR) say the backlog created by the virus has "exacerbated" issues linked to a lack of scanners, as well as shortfalls of 6000 radiologists and radiographers in the profession.

Prior to the pandemic, investment in new and upgraded imaging systems was part of the Government's ambitious cancer targets. The then Health Secretary Matt Hancock announced an extra £200m funding for new cancer screening equipment.

With greater access to state-of-the-art computerised tomography (CT) and magnetic resonanceiImaging (MRI), the NHS aims to ensure 75% of cancer diagnoses are made at an early stage (stage one and stage two) by 2028.

The Health Foundation said £1.5bn would be needed to bring the UK up to the required capacity. At the time, the UK had the lowest number of CT and MRI scanners per capita among the EU15 and G7 countries, with less than a third of Germany's machines. Advanced imaging technology and new working practices may close the gap between availability and demand for diagnostic imaging.

Accelerated imaging

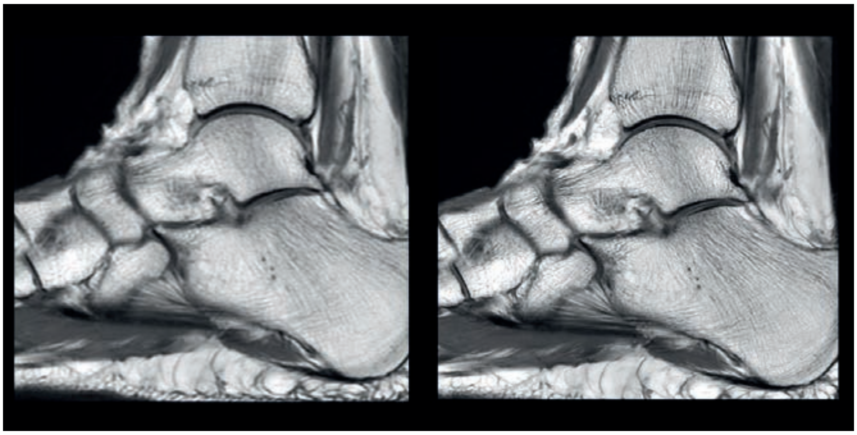
Due to low inherent signal in MRI, innovations are often targeted at reducing the scan duration. For upgrading of legacy systems, replacing 1.5T with 3.0T scanners can improve the signal by 30% to 60%. Newer equipment also comes with improved features, such as lightweight coils for MRI, more space within the scanner, and faster image reconstruction times in CT.

In CT imaging, research studies in compressed sensing, a type of image reconstruction, has shown dose reductions of 80% for near-equivalent image quality. Similarly, image de-noising based on convolutional neural network reconstructions has halved the noise levels in CT compared to previous iterative reconstruction algorithms. And in MRI, compressed sensing and deep learning techniques can reduce scanning time by 30% to 60%. See Figure ❶.

AI-supported diagnosis

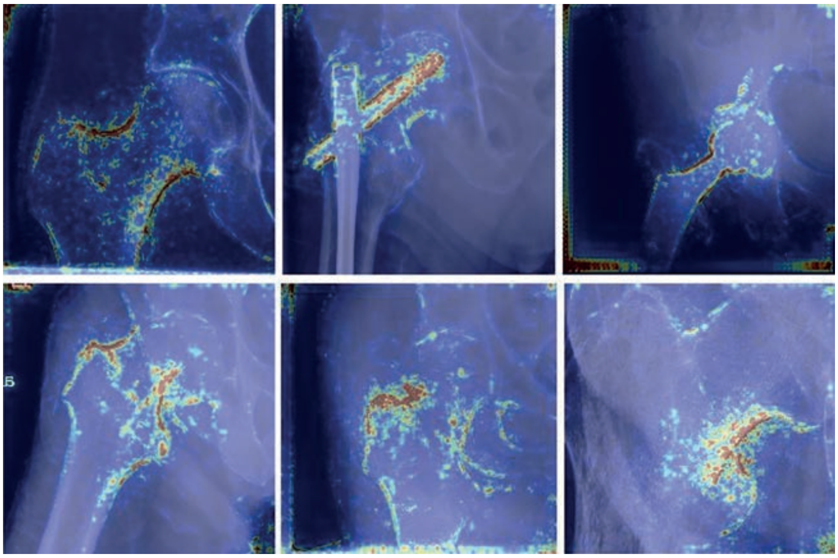
A new NHS artificial intelligence (AI) lab supported by a £250m investment from the Government aims to boost the role of AI within the health service. In clinical trials, AIs have shown outcomes as good as the leading doctors at spotting lung cancer, skin cancer and more than 50 eye conditions. There are many excellent

Figure ❶ MRI of an ankle showing conventional (1:59 min) vs. deep learning reconstructed images (1:18 min).



Reproduced courtesy of gehealthcare.co.uk

Figure ❷ Maps created by AI showing its decision-making process when evaluating hip X-rays. These images can be used for training, and they increase the speed and confidence of diagnostic reports.



Reproduced courtesy of Radiology: Artificial Intelligence

Krogue J D, Cheng K V, et al. Automatic Hip Fracture Identification and Functional Subclassification with Deep Learning. *Radiology: Artificial Intelligence* 2020. Published online March 25, 2020. Doi:10.1148/ryai.2020190023. © Radiological Society of North America.

applications of AI technology, but more work is needed to ensure these systems are safe and can be used ethically at scale. In orthopaedics, researchers have shown the decision making of AIs when evaluating X-rays improve the diagnosis of hip fractures made by doctors.

Maps created by the AI demonstrate its decision-making process when evaluating hip X-rays. These images can be used for training, and they increase the speed and confidence of diagnostic reports. See Figure ❷.

Dr Nicola Strickland, President of the RCR, said: "I expect radiologists to be leaders in using AI algorithms to assist them, provided they can see evidence that these AI algorithms have been developed using large enough, properly curated data rigorously validated and tested."

Imaging COVID-19

AI has been used in acute COVID-19 where lung X-rays and CT can predict if patients are likely to recover, or require admission to intensive care or ventilation.
This work has helped allocate resources and improve patient outcomes during the pandemic. More research is required to understand the impact of long COVID as one in 20 people are likely to suffer from COVID-19 symptoms lasting more than eight weeks.

A recent study in which patients inhale xenon gas during an MRI scan has identified damage not picked up by conventional scans. In patients who reported breathlessness, the scans showed signs of lung damage by highlighting areas where air is not flowing easily into the blood. Lung damage identified by the xenon scans may be one of the factors behind long COVID. See Figure ❸.

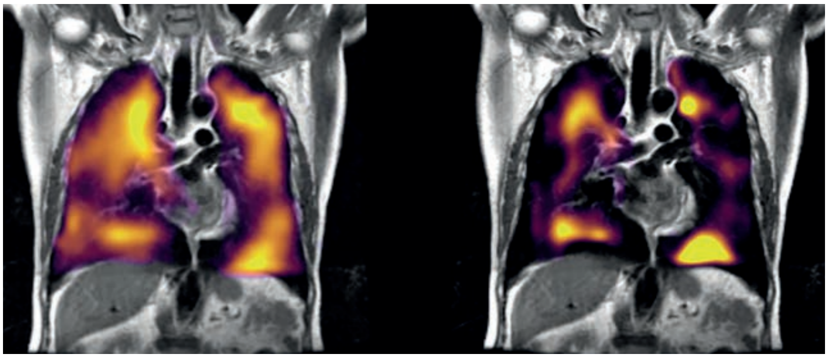
Working practices

Imaging patients with active COVID-19 has also posed a challenge as staff are required to wait a safe period of time for air exchange prior to disinfecting surfaces. UV disinfection robots may help decontaminate areas more quickly, without exposing staff to airborne coronavirus. UV-C ultraviolet light is used to destroy the virus by damaging its RNA so it can't multiply. While hazardous to humans, the robots are self-driving and can navigate around a room exposing surfaces to ultraviolet light and safely inactivating airborne coronavirus and other pathogens.

Integration of new tools is also reshaping clinical practice. Following a stroke, urgent brain imaging is performed to show areas of the brain with reduced bloodflow. Instead of applying time-based treatment rules, imaging allows doctors to plan treatment of stroke patients based on individualised brain tissue status. A significant shift towards precision medicine can lead to better outcomes for patients, with more discriminant interventions.

Investment in new and upgraded imaging systems, equipped with state-of-the art technology, will help increase the number and quality of diagnostic imaging studies. Integration of AI within healthcare may facilitate high-quality reporting, faster diagnosis and new image-based treatments. ◘

Figure ❸ In the scarred lungs, on the right, there are much larger areas of darkness, representing parts of the lungs that are having difficulty transporting oxygen into the bloodstream.



Reproduced courtesy of Radiology

Grist J T, Chen M, et al. Hyperpolarized ^{129}Xe MRI Abnormalities in Dyspneic Patients 3 Months after COVID-19 Pneumonia: Preliminary Results. *Radiology* 2021; 301:E353-E360.

COACHING

A tonic for your thoughts pt. 3

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

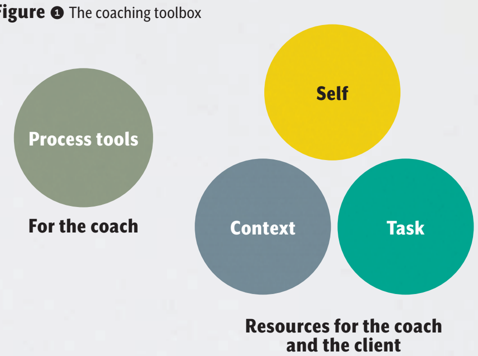
This is the concluding part of my mini-series, which aims to provide an introduction to coaching and how it might be used to good effect in the workplace.

In part one, I offered a definition for both coaching and mentoring, and compared and contrasted these two learning interventions. I then took a brief look at the evidence base and explored how the way we think affects our feelings and behaviours.

In part two, I described the coaching process and identified competencies for effective coaching. I then presented a model for a coaching toolbox and described the first section of this toolbox: process tools for the coach.

For this third and final part, I 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.

Figure 1 The coaching toolbox



Finally, I round off with a synopsis of my own journey, which I link to my recommendations to provide a personal reflection.

The toolbox

Figure 1 is a visual representation of the coaching toolbox that can be usefully divided into two sections: one for the coach to support them in the coaching process itself, and one containing resources for the coach to discover, share and use with clients.

The second section of the toolbox is a useful source of resources for the coach to draw upon to support their client. This is subdivided into three themes, which broadly align with the learning that occurs in a coaching setting: self-discovery, making sense of the current situation and changing something.

IMAGES: GETTY

"Know thyself" is one of four inscriptions carved into the temple of Apollo at Delphi, and which was later associated with Socrates. In 1974, Timothy Gallwey suggested that the biggest obstacles to success and achieving potential were internal, not external. This is relevant for coaching: a client will achieve significant transformation if they are truly willing to look at themselves. Self-discovery is a fundamental aspect of the coaching relationship and there are numerous resources to support this, including psychometric tools to discover personality preferences, questionnaires to look at learning styles, and tools and techniques covering topics such as personal resilience, emotional intelligence and self-belief.

Next, there is context. This relates to the client having a meaningful understanding of the situation they find themselves in and how they fit within the organisation and the wider system. Resources may relate to legislation, regulation, political systems, professional networks, standards and organisational policies, strategies, business plans and initiatives.

The final part of the toolbox is potentially the largest, as this covers all the various models, methods, templates, tools and techniques that a client might use to support them in achieving their objectives. This part of the toolbox could be seen as the "technical know-how" section. Resources may relate to leadership knowledge (for example, John Adair's action-centred leadership model (Figure 2), and numerous other topics, such as having challenging conversations, time management, improvement science, project management and option appraisal.

Just as the agenda is set by the client, the client will also have their own toolbox, and they will likely draw upon and develop this during coaching. The coach will not be seeking to replicate their clients' toolboxes; instead they will be logging references for resources which they feel may be useful for future clients.

Recommendations

Whether formal or informal, all coaching encounters have this in common: they happen in the conversations between individuals. Anyone could use the GROW model to help structure a future conversation. Role and seniority are immaterial – a training coordinator could have a coaching conversation with a trainee about their portfolio, in the same way that a senior leader could have a coaching conversation with a key stakeholder about a project. And there are plenty of applications away from the workplace. So my first recommendation, for anyone and everyone, is take a look at the GROW model and just give it a go. Your organisation may well offer "how to have a coaching conversation" masterclasses that would help with this.

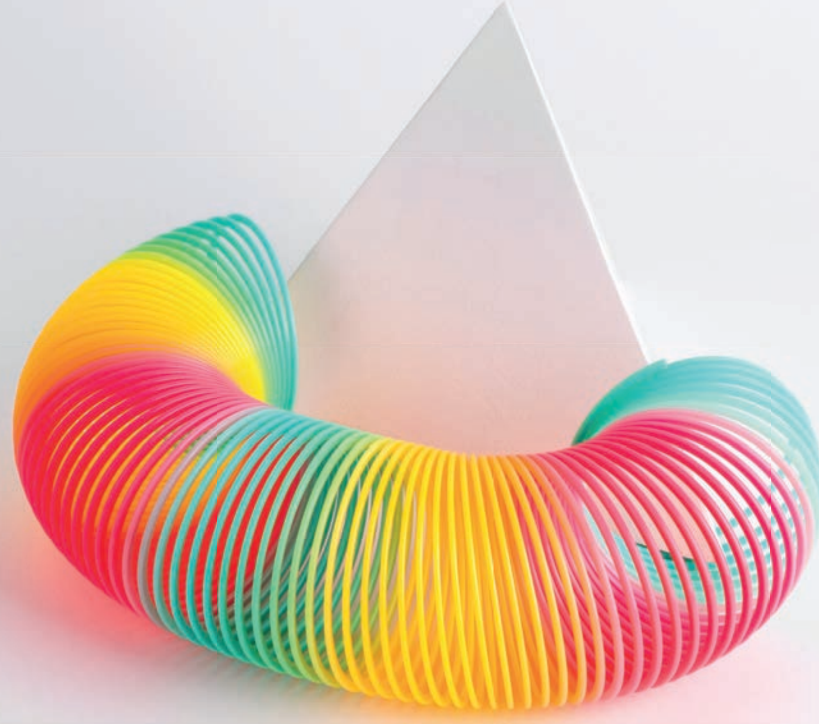
My second recommendation is to consider coaching for yourself when you are reviewing your own development needs. Find out whether your organisation has an internal coaching offering. For NHS trusts, coaching might be offered internally, through a local network or via the NHS Leadership Academy. This is likely to be particularly useful for consolidation learning and if you are taking on a new role, which includes leading and managing individuals and teams. Equally, coaching can provide effective support for leaders promoted into senior positions.

> **"COACHING IS A STRUCTURED CONVERSATION AIMED AT IMPROVING A SITUATION FOR SOMEONE**

My third recommendation is for line managers. Coaching approaches can make normal managerial conversations more productive. I'd recommend that you seek out some coaching tools and adopt these when you interact with your team as part of your day-to-day role.

Coaching is a leadership skill, and for anyone considering options for their leadership and management development, this should be a consideration; this is my fourth recommendation. A variety of development options are available ranging from foundation workshops to certified training leading to recognised qualifications. If you are interested in a coaching qualification, you may also be interested in becoming part of your organisation's coaching offering.

The use of coaching skills can improve a mentoring relationship, particularly when identifying key issues and working through options. If you mentor others, my fifth recommendation is for you – and that is to take look at coaching tools to identify what you could adopt to enhance your mentoring offer.



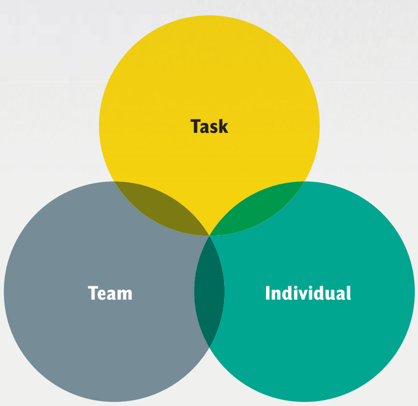
My journey

My professional journey is no doubt similar to many others, particularly in the transition from delivery to directing as I took on more senior roles. Broadly, this has been a journey of three stages, which I describe below. I also comment where, upon reflection, it would have been useful to have taken heed of the recommendations I describe above, had I known about them.

My early career was characterised by my interest in the science and the technology and how this is managed in a healthcare setting. At some point I became an "accidental manager" and also at some point I realised that I needed to do something about this. I needed to look at my own self-belief and pay attention to my own behaviours and actions. Managing people was, at first, a necessity (and somewhat mysterious and unpredictable), but over time I became increasingly curious about what worked, what didn't, and how I was able to influence outcomes. Being aware of and adopting coaching approaches and tools around the time of picking up line management responsibilities would have been useful.

The second stage of my journey was a period of consolidation and development working in a senior leadership role. This involved working at operational and strategic levels and developing my networks. Dealing with workplace conflict came with the territory and I decided to train as a workplace mediator and join the organisation's mediation team. I also had my first experience of coaching as a client, which was part of my organisation's leadership development programme. These were significant steps at becoming better equipped to work with and support others. Having access to coaching as a client earlier in my career would have been useful, particularly when there were significant changes in my role.

Figure 2 John Adair's action-centred leadership model



Transition into stage three has occurred latterly and this is characterised by a marked shift in my interests, from "the technical" to "the people". I recognise now that I had been adopting a coaching leadership style, although I remained largely incognisant of this until engaging in formal ILM7 coaching training, which for me has been a sense-making experience. Being aware of and pursuing a coaching qualification somewhat earlier in my career would have been useful.

> "I NEEDED TO LOOK AT MY OWN SELF-BELIEF AND PAY ATTENTION TO MY OWN BEHAVIOUR

Seeing my colleagues being courageous and successful has provided me with some of my most rewarding professional experiences.

Conversely, my most challenging experiences have involved dealing with behaviours individuals were choosing to adopt. I believe it is significant to acknowledge that these experiences, at the extremities of both "rewarding" and "challenging", have related to behaviour rather than scientific knowledge and skills.

Concluding comment

Stripped back, coaching is a structured conversation aimed at improving a situation for someone. As a profession, we are naturally curious and proud of that – so let's be curious about coaching.

Andy Nevill *is a Consultant Clinical Scientist at Royal Devon and Exeter NHS Foundation Trust. For references to accompany this article, email rob.dabrowski@redactive.co.uk*

IMAGE: ISTOCK

PPE PRODUCTION

Collaboration in the pandemic

Dr Alexander Lunt and **Dr Benjamin Metcalfe** on how the University of Bath helped the Royal United Hospital during the COVID-19 pandemic.

As the global COVID-19 pandemic accelerated, and case numbers rose in the spring of 2020, it became clear that hospitals and healthcare providers were struggling with the supply of basic medical equipment.

At the forefront of the supply issue was a lack of personal protective equipment (PPE), and while the national situation varied between trusts there was a growing realisation that NHS supply chains were potentially unable to provide the required PPE. There were also increasing concerns about the supply of equipment such as ventilators and pulse oximeters. Faced with these threats, and amid the backdrop of a worsening pandemic, the Royal United Hospitals NHS Foundation Trust (RUH) in Bath turned to the University of Bath for support.

Reaching out

The RUH provides acute treatment and care for a catchment population of around 500,000 people in Bath, and the surrounding towns and villages in north-east Somerset and west Wiltshire. The University of Bath is a public research university founded in 1966; it has major strengths in engineering and the physical sciences and currently has over 2000 academic staff and 18,000 students. Despite their close geographical


1 More than 400,000 items of PPE were delivered to regional front-line teams

relationship, the university being based on the hills overlooking the city, the collaborative work between the RUH and the university has, in recent years, primarily been based on an informal relationship and individual contacts. However, like many of the great innovations inspired by COVID-19, this all changed during the first days of the pandemic.

A group of academics within the university's Faculty of Engineering and Design were discussing the highs and lows of lockdown when they decided to reach out to the RUH and see if its skills could help. A connection was rapidly formed and Dr Andy Georgiou, The RUH's Lead Consultant for Intensive Care, jumped at the chance to task the university with finding solutions to their needs. The Bath team, led by Dr Alexander Lunt, Lecturer in Mechanical Engineering, started by looking at ways to make hospital ward equipment, such as trolleys and cabinets, more COVID secure. This helped to reduce the time-consuming cleaning regime that had to happen every time equipment moved in and out of wards.

Designing and manufacturing PPE

The project soon started to attract the interest of not just engineers, but also physicists, technicians, and support staff at the university. Within a few weeks, the number of active projects had ballooned; academic staff offered advice and ran simulations to pave the way for ventilators to be adapted for use with two patients, and a low-cost and open-source pulse oximeter was designed and trialled as a front-line triage device. Thankfully the number of ventilators and pulse oximeters available in the UK continued to meet demand, although this work has since proven invaluable in driving new research into the possibilities of shared ventilators and the performance of pulse-oximeters on non-white patients.

However, the main contribution within the collaboration was the design and manufacture of PPE. At a time when university laboratories were being shut down, staff were being furloughed, and students were sent home, the university started to ramp up production of face shields, gowns, and eye protectors. Initially a group of four people started out by reverse engineering face shields provided by the RUH, and once a design had been selected the production team quickly ramped up to over 70 volunteers from across the university. This activity was supported both directly by the university and by donations from generous individuals, local business and the community. At a time when most industries were closing down, the

FAST FACTS

+7000
working hours donated to create

128,000
face shields

9000
surgical gowns

200,000
eye protectors

"A TRIUMPH FOR HUMANITY, COLLABORATION AND GENEROSITY OF SPIRIT

university management recognised the importance of this activity and facilitated the opening up of its facilities in support of the local hospital.

Over 7000 working hours were donated, and the result was that the team produced 128,000 face shields, 9000 surgical gowns were stitched together by the costume design department from the nearby Bath Spa University, and over 200,000 eye protectors were made with support from local manufacturers. What began as a series of WhatsApp messages early in the pandemic culminated in the production and delivery of over 400,000 items of PPE to regional front-line teams including the RUH.

The team scooped the Setsquared #MakingItWork Award for their efforts and have already received local and national recognition. This has taken the form of a ceremony hosted by the Chancellor of Bath University, His Royal Highness The Earl of Wessex, a visit by the Minister of State for Universities, Michelle Donelan MP, a letter of thanks from the Lord Lieutenant of Somerset and numerous awards.

FRONT-LINE SUPPORT

TO THE RESCUE

DR ALEXANDER LUNT FROM THE UNIVERSITY OF BATH

"This project started as a way for a small group of engineers to support those caring for us on the COVID front lines. It has been a great honour to help relieve even a small element of the burden that has been placed on the NHS during this difficult period. The support for the project has been incredible and the recognition for all members of the team has been outstanding. However, for me it's the personal letters of thanks that have highlighted the importance of the work. We've received so many from people saying they've been wearing our PPE and without it, they wouldn't have felt half as safe."

DR ANDY GEORGIOU FROM THE RUH

"In the midst of the COVID-19 pandemic the University of Bath came to our rescue by supplying a reliable supply of effective face shields. These supplies could not have been more timely; face shields began arriving from the university within 24 hours of our expected exhaustion of supplies, which was nothing short of a god-send. Subsequently, we found ourselves in the incredibly fortunate position whereby they could sustain the hospitals requirement for face shields entirely. The staff in the ICU, but also in the rest of the hospital, will forever be indebted to the staff and volunteers for protecting them in our hour of greatest need. They have literally been life-saving."

The PPE designs have already been shared with the UN-run Social and Development International so they can be distributed to developing countries, and several journal papers have been written, explaining both the processes and the technical details of several of the innovations.

The impact of saving lives

Libby Walters, Interim Chief Executive of the RUH, said: "We continue to be incredibly grateful to the University of Bath, and Bath Spa University too, for their support. The face shields and gowns that have been produced for the RUH, free of charge, have helped to keep our front-line staff safe while they care for some of our most seriously ill patients."

Professor Tim Ibell, Dean of the Faculty of Engineering and Design, said: "This extraordinary effort is such a wonderful example of the societal benefit which a university can offer in its civic setting when it partners with local health providers, businesses and donors. Nothing shouts impact more than saving lives, which is exactly what this PPE production scheme was all about. A triumph for humanity, collaboration and altruistic generosity of spirit." See panel, left, for further reflections from the university and the RUH.

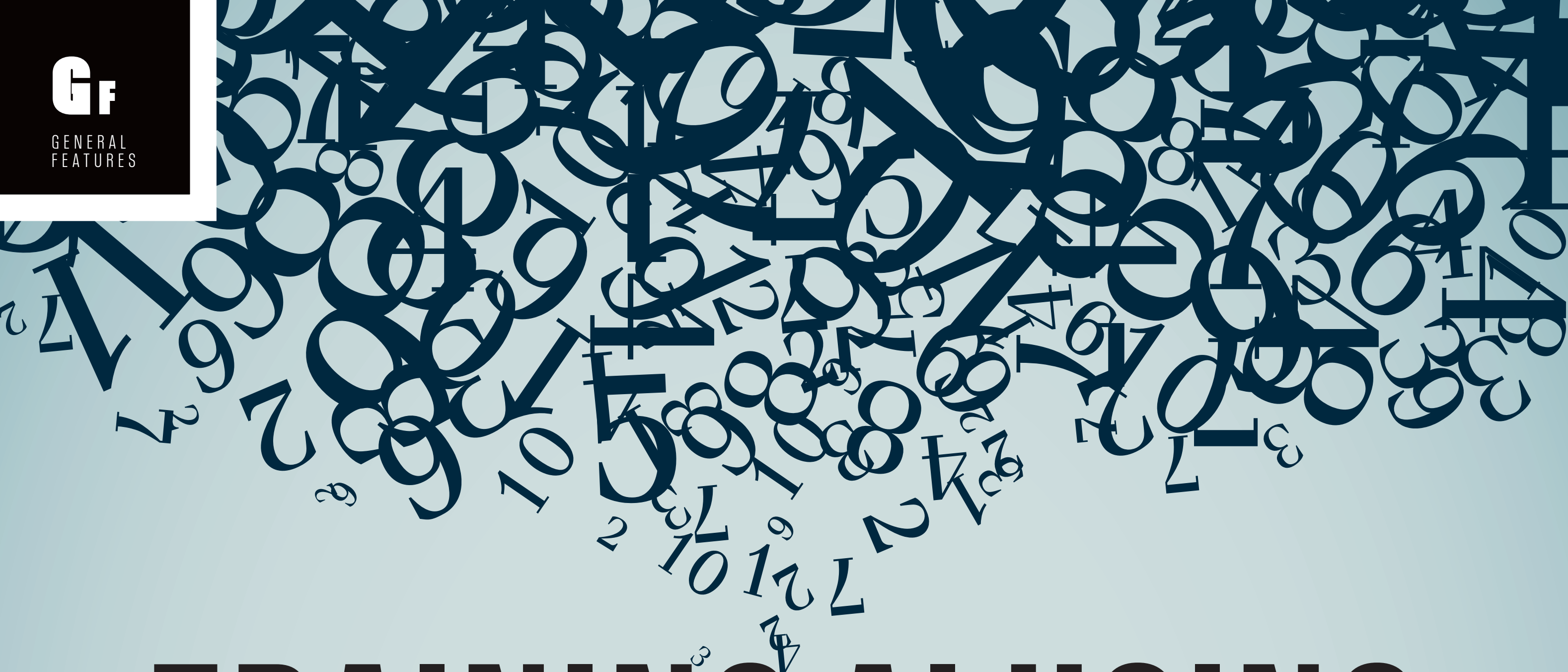
A long legacy

While the production of PPE has now ended, the legacy of the project lives on. The collaboration has demonstrated the immense power of community spirit during a time of national and international crisis, but it has also highlighted to many what can be achieved when institutions work together.

Maintaining the historical links between clinical engineering departments and academic institutions is a challenging task, that is not made easier by ever-increasing clinical workloads. This situation risks a reduction in collaborative research projects, and the significant potential clinical impact that can be achieved through these routes. Stronger formal links between universities and trusts would foster innovation across all areas of clinical practice, from medical device design, training and support in the use of artificial intelligence, and procedural and efficiency improvements.

The RUH and the University of Bath may only be separated by a hill, but sometimes it takes a global pandemic to realise what we can achieve when we work together.

Dr Alexander Lunt *is a Lecturer in Mechanical Engineering and* **Dr Benjamin Metcalfe** *is a Lecturer in Electronic and Electrical Engineering, both at the University of Bath.*

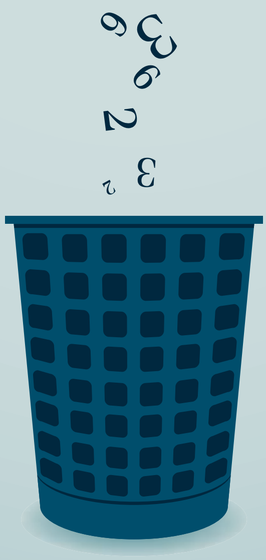


TRAINING AI USING ARTIFICIAL DATA

Rubbish in, rubbish out?

Dr John Tracey and colleagues look at the role of AI in automated quality assesment and how to train neural networks.

Artificial intelligence (AI) is becoming increasingly prevalent in medical imaging, and it is likely that clinicians will encounter such systems during their career. Due to the somewhat recent advances in personal computing power and accessibility to an array of AI algorithms, designing AI-based systems is now well within the grasp of most researchers. It is even possible that small AI projects can be carried out using off the shelf hardware. For example, the project discussed here was carried out using a gaming laptop. Most systems designed in this way will often be used in a more supporting role. This isn't to downplay the usefulness of such systems – one can almost think of AI support systems as an extra staff member!



Neural networks

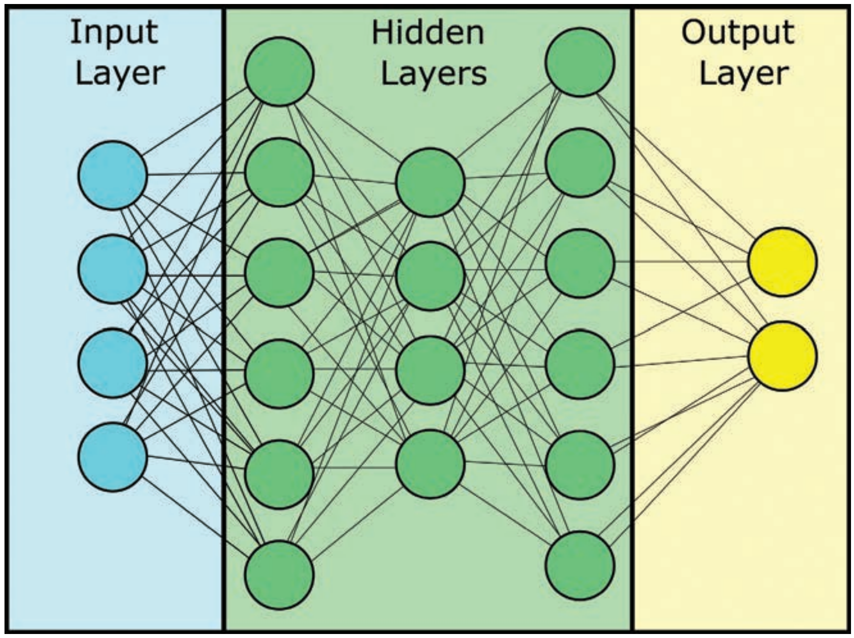
Neural networks are often the first thing that comes to mind when one considers AI-based systems. Neural networks provide high degrees of predictive power for a wide variety of tasks. A neural network essentially consists of a series of interlinked neurons (see Figure 1). Data then passes into a neuron, activates it, then sends the signal onwards to other neurons. The magnitude of this activation is what is being tuned in a neural network. Modern neural networks contain thousands of neurons over hundreds of layers. The actual network becomes a complicated interconnected system, but overall this system can be considered simply as a function (albeit quite large) that can be written down. This function is based on the

IMAGES: ISTOCK

number of neurons and layers – a greater number results in a more complicated function, which is able to learn more complicated details. Essentially what a neural network does is fit this function to whatever data we have presented to it. This is how machine learning and neural networks differ from traditional computation methods. Classically, as scientists we strive to always understand the underlying physics and processes that drive the distribution of the data. Through the use of AI there is no longer the need to understand these processes. The network works it out for us. That being said, researchers must be careful about the data they use: rubbish in, rubbish out!

In practice, this is done by providing the neural network with many (often thousands) of examples of the data. For example, in the case of a cat-dog classifier the network would be shown images of cats and images of dogs. For each sample we check if the network got it right or wrong, then by using some minimisation algorithm (such as steepest descent) the coefficients of our function are adjusted to allow the function to better fit the data. By iterating this process several times, the network begins to learn the general features of cats and dogs. Therefore, at some later date, we can show the network a picture of a cat it has never seen before and the network should be able to extract the general features and correctly identify it as a cat.

Figure 1 Typical neural network



Artificial data

Neural networks require a large database, which can often be a bottleneck in neural network studies. One solution does exist: artificial data. Artificial data is challenging to produce since any subtle imperfections can be learned by the network, degrading performance. But if high-quality artificial data can be produced, you have little bounds to the size and diversity of the generated dataset. One such candidate for artificial data usage occurred within the magnetic resonance imaging (MRI) unit at NHS Highland. One of the clinical MRI scanners at Raigmore Hospital had a coil element malfunction that manifested as a shadow over the image near the damaged coil element (see Figure 2). Given the natural variation in patient images combined with differences in coil placement between patients, this malfunction wasn't discovered by radiographers or radiologists, or identified through daily quality assurance (QA) for nearly a month. It thus provided a set of 109 patient images showing the distinctive shadow of coil element failure. With a reasonably sized real dataset for testing, a project was devised to determine if an AI solution could be developed to identify coil failure in patient images. This would essentially facilitate constant surveillance of patient images and provide an adjunct to phantom QA and first-line image quality review from staff.

> **"**
> **THE COEFFICIENTS OF OUR FUNCTION ARE ADJUSTED TO ALLOW IT TO BETTER FIT THE DATA**

The small set of images with coil element failure was not enough to train a neural network (but did suffice as a test set), so artificial data was considered. Machine-based artefacts can be very deterministic and present in a similar fashion regardless of the patient. This makes such problems exploitable by artificial data.

In this project the coil sensitivity profiles were determined from a volunteer scan. By simulating the position of the receiver body coil on patient data without coil element failure, the sensitivity profiles could be applied to each patient to determine the image signal distribution detected by each coil element. Thus it was possible to deconstruct the image into a series of coil images. By nullifying some of these coil images and applying a reconstruction algorithm matching that of the scanner, high quality artificial data was created. An example of such data is shown in Figure 2.

This method does rely on a vast database of artifact-free images, but this is often of little concern within a busy clinical MRI unit. The neural network was then trained

" THE TRAINED AI WAS FOUND TO DETECT COIL FAILURE ON THIS DATASET WITH AN ACCURACY OF 92%

on this artificial dataset, where the network classified each image as either containing coil failure or not. The trained AI was then tested on the dataset of 109 images with real coil element failure which it had never seen. It was found to detect coil failure on these images with an accuracy of 92% – a very good result when one considers the network had never actually seen any images of real coil failure prior to this.

Future uses

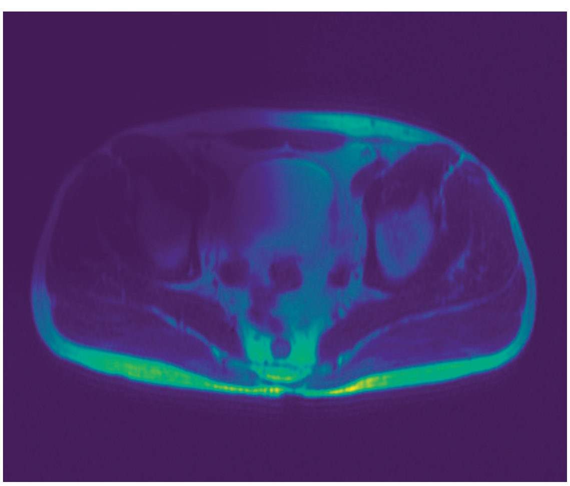
In some ways the AI could be considered to be like a new staff member who had been trained to vet the clinical images for coil failure. Given this, it seemed sensible to compare the accuracy of the algorithm to that of radiographers whose role it is to undertake first-line image review to identify machine- or patient-related issues. To test the efficacy of the algorithm, five radiographers were presented with a selection of clinical images with and without coil element failure. The group achieved an average accuracy of 60% in identifying the image with failure. At an accuracy of 92% the AI algorithm showed a significant improvement in this task demonstrating the utility of such a tool.

Our goal is for this AI to be deployed within NHS Highland to undertake a prospective evaluation of the algorithm to determine if it can detect coil failure from patient images in real time. When continuous failures are detected, a notification will be sent to physics staff to investigate the issue. Systems like these potentially provide a useful adjunct to routine QA providing a method for early detection of potential scanner issues.

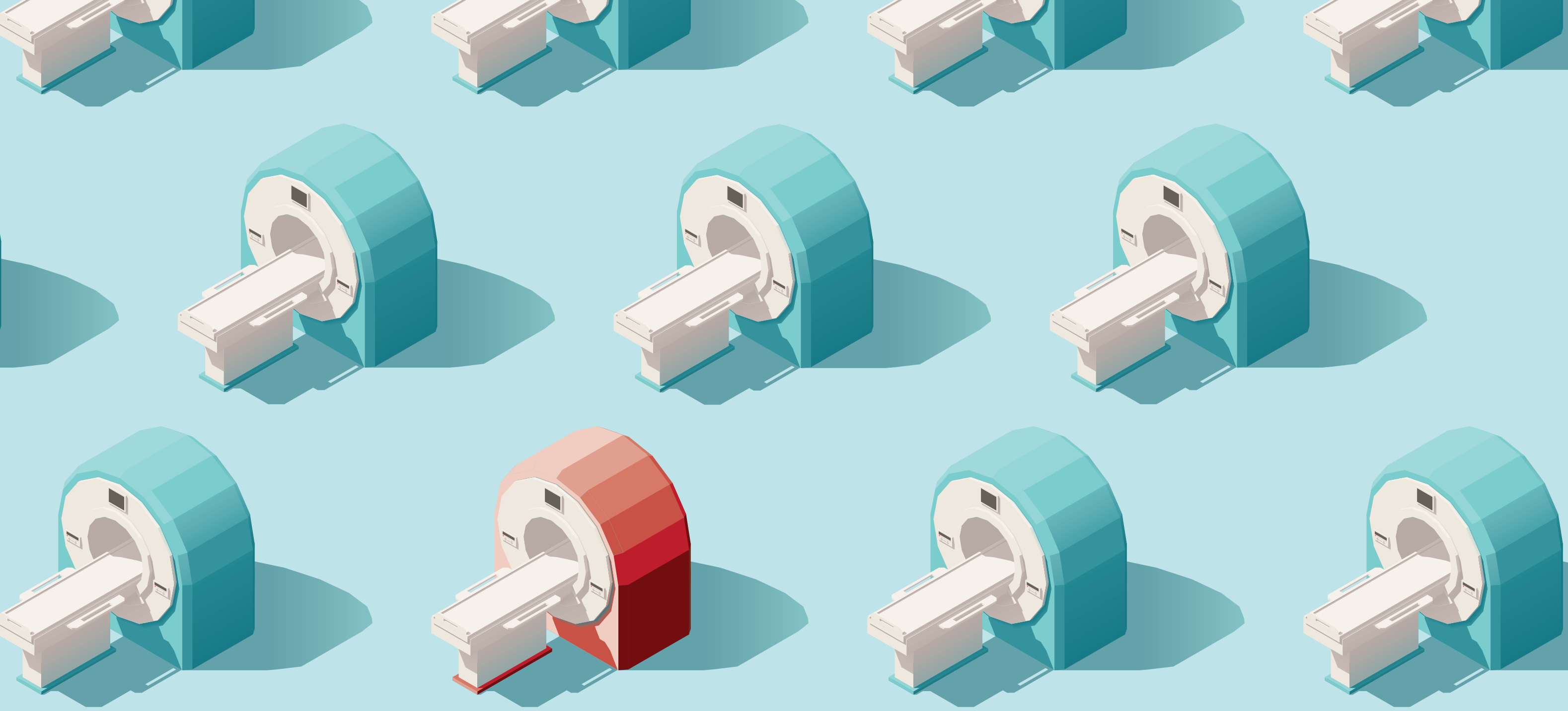
Although in this case artificial data was designed for the very specific issue of coil element failure, there is no reason other machine faults can't be considered. Other failures such as resolution dropout due to gradient malfunction could easily be implemented. In principle, one can design an entire suite of AIs, where each one is trained to detect a particular machine fault. It would provide the benefit of real-time scanner monitoring, ensuring any problems are detected as soon as they occur, this has the potential to save both human and scanner resources – important factors in overburdened clinical departments.

Simulation of artificial data is also highly applicable to other modalities. In principle, if one could implement the reconstruction algorithm used in computed tomography (CT), it would be possible to produce artificial data that exhibits detector failure by following a similar method to that presented here. Considering the highly predictable nature of machine faults and the usability of modern neural network frameworks, developing artificial data for use in training neural networks has great potential in automating QA.

Figure 2 Example of artificial data showing coil failure



Dr John Tracey *is a Trainee Clinical Scientist and* **Dr Jonathan Ashmore** *is a Principal Clinical Scientist, both at NHS Highland.* **Dr Laura Moss** *is a Research and Development Healthcare Computer Scientist at NHS Greater Glasgow & Clyde*



HARMONISATION

in nuclear medicine

Panayiotis Hadjitheodorou looks at harmonisation of quantification and radioactivity cross-calibration at the German Oncology Center.

Nuclear medicine is a fast-evolving field that is seeing a huge wave of advancement as technological developments allow previous limits to be exceeded. However, the lack of harmonisation of quantification in nuclear medicine imaging renders all these new and impressive technologies, techniques and workflows a burden in the process of optimisation and clinical research.

The simplest form of harmonisation is to force patients to have all follow-up scans performed on the same scanner (detrimentally impacting their personal life, potentially forcing people to relocate or travel large distances repeatedly) to allow for the quantification of the standard uptake value (SUV) and any other parameters to be comparable, or to even make any sense. Despite the newest scanners having better detectors, electronics, computing power and reconstruction algorithms – all resulting in a better image – the measurements that are recorded for the quantification of malignancies or any other reason are highly impacted by these features, as shown by previous research.

This article sets out the workflow required to solve these problems. The German Oncology Center's nuclear medicine department used the accreditation process offered by the European Association of Nuclear Medicine (EANM), Forschungs GmbH and Research4Life (EARL), which, according to EANM, is an initiative to promote research and multicentre nuclear medicine by "improving nuclear medicine and its practice, providing a basis for discussion and the exchange of cutting-edge ideas, acting as a contact point for researchers as well as for clinicians and business leaders, providing a platform for the efficient pursuit of scientific initiatives, facilitating multicentre research projects, enhancing the comparability of data acquired by molecular imaging, boosting molecular imaging so that it becomes a standard diagnostic modality in future clinical medicine and research and positioning nuclear medicine within the EU research agenda".

EARL offers accreditations for 18F-PET/CT studies (Standards 1 and 2), 18F/11C Brain PET/CT (newest addition for 2022 – 18F Standard 2 is a prerequisite), a 89Zr PET/CT accreditation and a 68Ga PET/CT accreditation (18F Standard 2 is a prerequisite). Currently, out of all the PET/CT centres in the UK, only four departments have taken advantage of this opportunity; two departments have been accredited for 18F (Standards 1 and 2) and two for 18F (Standard 1).

The department's workflow is minimally affected by each of the accreditations chosen to perform. This is because the accreditation process uses the same equipment (slightly modified procedures) and is performed at the same frequency as the tests suggested by IPEM Report 108 (Quality Assurance of PET and PET/CT Systems). The quality control (QC) tests that were documented and published in the EANM standards in 2010 are the foundation for the EARL accreditation. The new standard (Standard 2) enables sites to take advantage of cutting-edge PET/CT technology (such as time-of-flight, point spread function and block sequential regularised expectation maximization reconstruction algorithms), and it is based on a recent EARL article by Kaalep *et al* (2018). This article investigated a variety of PET/CT scanners by various manufacturers and models as well as a variety of reconstruction algorithms to include Philips: Vereos 1, Ingenuity 1 and 2; Siemens: Biograph mCT Flow 1-3, mCT 1-6; GE: Discovery 710 1-2, Discovery MI 1 and 2 and GE Discovery IQ with various reconstruction algorithms including Q.Clear.

Kaalep *et al* (2019) describes the influence of the new 18F Standard 2 on the quantification of clinical investigations (non-small cell lung cancer and lymphoma PET-CT studies). According to Kaalep *et al*, different volume of interest (VOI) techniques achieved similar results with regards to standardised uptake value (SUV) metrics; however, variations in metabolic active tumour volume (MATV) as well as total lesion glycolysis (TLG) have been observed. Therefore, the application of EARL2 standards can result in higher SUVs, decreased MATV and slightly modified TLG values relative to EARL1.

The procedure for the accreditation is simple and straightforward. The accreditation enrolment form is filled in and submitted, EARL user credentials are created, the calibration is performed and image quality QC tests are submitted for analysis to the EARL team. Following approval of the submitted data (or requests for additional measurements to improve the results), a calibration QC is submitted quarterly. After equipment accreditation, the accreditation certificate and the signet will be available for use, and the institution will be listed on the EARL website in the Centres of Excellence network section.

The nuclear medicine department of the German Oncology Center applied for the 18F PET/CT studies, for both Standards 1 and 2, for their GE Healthcare Discovery IQ PET/CT scanner. For Standard 1 the image reconstruction is performed using GE's Ordered Subset Expectation Maximisation (OSEM) algorithm (4 iterations, 12 subsets, filter cut-off 7mm), while for Standard 2 the image reconstruction is performed using the GE's OSEM with PSF algorithm (5 iterations, 12 Subsets, Filter cut-off 5mm).

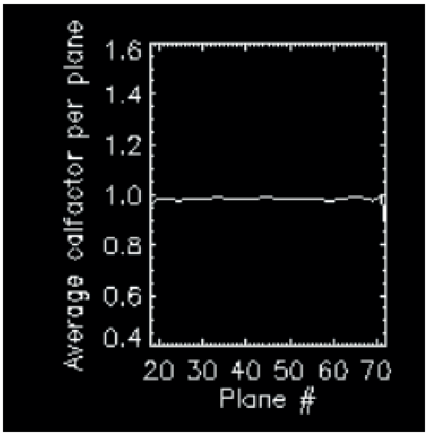
Since the main point of this article is harmonisation of quantification, the first thing that needs to be performed is radioactivity cross-calibration. According to IPEM Report 108, "to convert the reconstructed pixel values in the PET image from counts into absolute radioactivity concentration, the system must be calibrated against a known amount of

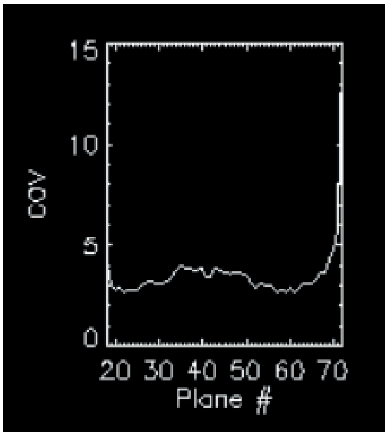
Table 1 The following table shows the SUV recovery coefficients for 18F Standards 1 and 2 effective as of quarter 3 2020:

NEMA IEC phantom spheres		18F standards 1 RCs		18F standards 2 RCs		
Diameter (mm)	Volume (mL)	max	mean	max*	mean	peak**
37	26.52	0.95 – 1.16	0.76 – 0.89	1.05 – 1.29	0.85 – 1.00	0.90 – 1.10
28	11.49	0.91 – 1.13	0.72 – 0.85	1.01 – 1.26	0.82 – 0.97	0.90 – 1.10
22	5.57	0.83 – 1.09	0.63 – 0.78	1.01 – 1.32	0.80 – 0.99	0.90 – 1.10
17	2.57	0.73 – 1.01	0.57 – 0.73	1.00 – 1.38	0.76 – 0.97	0.75 – 0.99
13	1.15	0.59 – 0.85	0.44 – 0.60	0.85 – 1.22	0.63 – 0.86	0.45 – 0.70
10	0.52	0.34 – 0.57	0.27 – 0.43	0.52 – 0.88	0.39 – 0.61	0.27 – 0.41

*SUVmax for total body PET/CT scanners is under investigation
**SUVpeak limits are under a revision

Figure 1 Example of plane average SUV and plane by plane COV (%) analysis of the calibration QC reconstructions





Average volumetric SUV bias equals - 1.86514%. Should be within -10% and + 10%

radioactivity". The cross-calibration phantom (usually supplied with the scanner for the quarterly calibrations) consists of a uniform cylinder (of specific size) to which a known volume of water and a specified amount of 18F is added. The 18F is measured using a radionuclide calibrator with an 18F primary standard traceability. After a specified imaging and reconstruction protocol is followed, the EARL team calculates the cross-calibration factor, which convert cps into Bq ml^{-1}, and the slice sensitivity and efficiency correction factors (see Figure ❶.). This is repeated every quarter of the year on specific dates (in addition to every major service or software/hardware changes).

Image processing and analysis

For the second part of the QA test, the Image Quality NEMA NU-2 2001 phantom is used. The phantom consists of a cold 'lung' insert, six hot spheres of variable sizes which are surrounded by a specific background activity mixture (1:10 background to sphere activity ratio). The phantom is scanned using a specific imaging protocol and a reconstruction for each standard applied is created and sent to the EARL team for analysis. The SUV recovery coefficients (RCs) (background – spheres) for 18F Standards 1 and 2 are calculated for each sphere (VOI) according to the supplied information regarding the injected and residual activity, and the administration and imaging time details. The RCs for each SUV (max, mean, peak) are calculated as the measured activity concentration in the sphere (KBq ml^{-1}) divided by the actual activity concentration in the sphere (KBq ml^{-1}). The RCs are adapted for background and the maximum pixel value in each sphere.

If any of the RCs is not within range, the EARL team will notify the designated communication person of the issue and will suggest remedial steps, i.e. change in the reconstruction parameters. After the successful attempt for each of the standards is applied the department will be notified and the certificate for the accreditation is sent along with the EARL signet.

By becoming an accredited PET/CT centre of excellence, we can compare, exchange and combine PET/CT findings, including SUVs, as all data is collected and processed in a standardised manner. It can promote better research results and the reassurance that any patient that has been scanned on an accredited scanner can have comparable quantifiable results without being bound by geographic limits.

Figures ❷ to ❹ show how the recovery coefficients for the different sphere sizes of the NEMA IEC phantom vary for Standard 2

Figure ❷: SUV_{mean} recovery coefficients of Standard 2 vs sphere volume

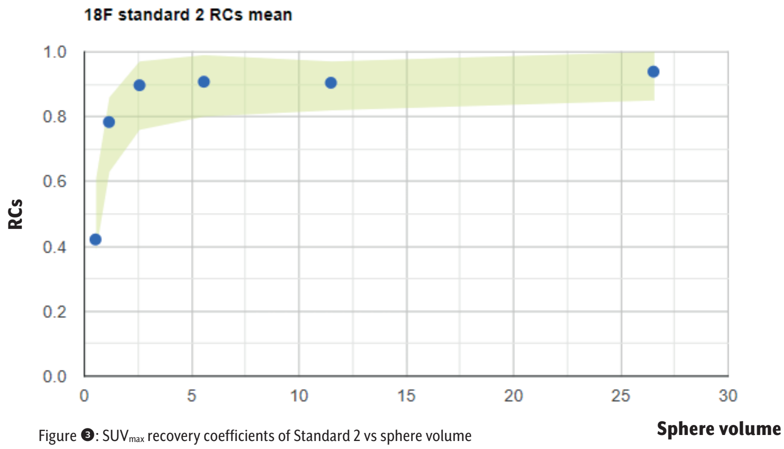


Figure ❸: SUV_{max} recovery coefficients of Standard 2 vs sphere volume

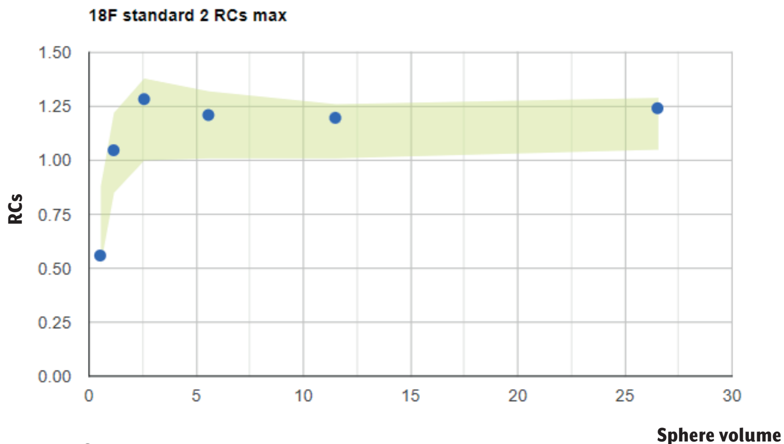
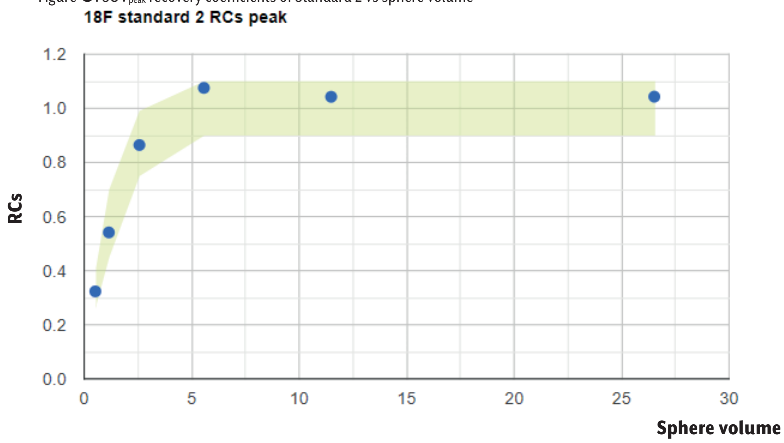


Figure ❹: SUV_{peak} recovery coefficients of Standard 2 vs sphere volume



Panayiotis Hadjitheodorou *is Deputy Medical Physics Coordinator - Nuclear Medicine, at German Oncology Center in Limassol, Cyprus.*

EQUIPMENT FLOW

Redesigning clinical engineering

Principal Engineer **Stephen Bond** explains how his department at the University Hospitals Plymouth NHS Trust was rethought.

The clinical engineering (CE) department within University Hospitals Plymouth NHS Trust has nearly 50 staff and uses 51,000 devices.

Like many CE departments across the country, the physical space we occupy, often late in design stage, largely dictates the flow of work and the procedures that then support it. Over time, there is always a risk that these become so well established and embedded that even the use of the facilities, rooms and layouts becomes rooted in purpose and resistant to change.

Fact-finding missions

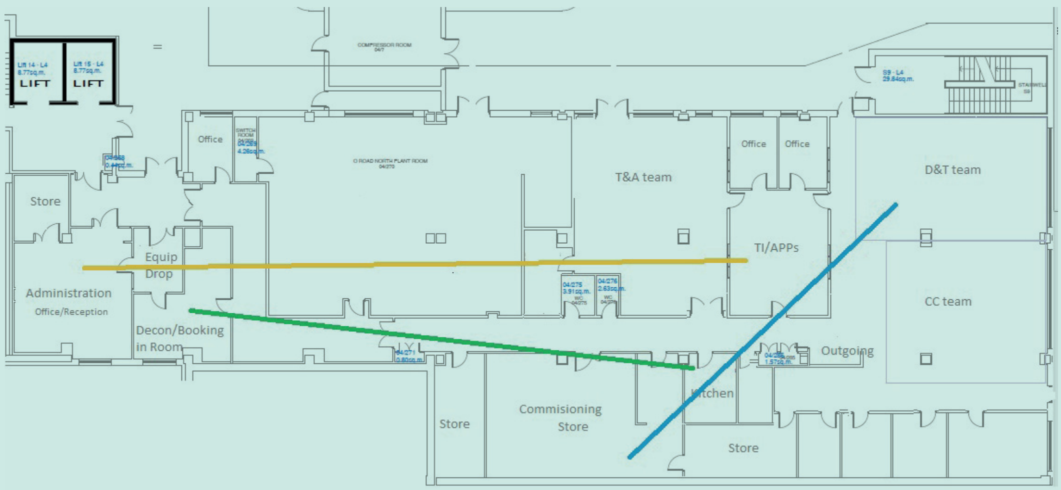
Within CE, recognising the risks around embedded and established practices, we engage from time to time in fact-finding missions – mini tours of other CE departments to look for best practice, innovation and ideas. A tour held many years ago helped shape our current department teams, form and function, and with many new staff in the department since then, we undertook a similar tour in 2019. We visited Cardiff (a site from an earlier tour), Birmingham and Nottingham CE departments.

Armed with a departmental SWOT (strengths-weaknesses-opportunities-threats) analysis, developed with department-wide input and deriving a series of questions from that, we were hosted by each site for a day to see how they operated, discussed their challenges and had an insightful facilities exploration of each.

Lesson learned

Upon our return, the lessons learned and an array of facts were fed back to the department through presentations and a report. That led us to open the door to suggested improvements for our own department. One of the most steadily supported suggestions we received was to move our admin team from the middle of the department to the front of house. At the time, in 2019 and before the pandemic, the department (main CE only, not including Medical Equipment Library

Figure 1 Clinical engineering moves: admin/apprentices swap (yellow), D&T team and commissioning store swap (blue), decon room move (green).



(MEL) and Specialist Mechanical Workshop) can be seen in Figure 1.

At that time, the equipment flow through the department was also either delivered direct to the MEL, to then be brought by MEL staff to CE following any additional cleaning, or directly into CE itself. Equipment also flowed from CE to MEL as a twice or more daily occurrence.

Like devices, visitors were also led into the department past offices, storerooms and technical areas long before reception or booking in and then onwards or backwards down the corridor to the teams. The decon room was infrequently used and then only for devices that arrived anonymously without a decon certificate or were found at booking-in to require additional cleaning.

Despite the general consensus on the desire to move the admin team to front of house, as often happens, the pace of change lacked that initial impetus and the move was not completed.

The pandemic

Then came 2020 and with it, COVID-19, social distancing, shielding, 2m spacing marks in corridors and everything else that became the new normal as we continued to repair, maintain, commission and manage an ever-increasing number of devices from within the hospital and without.

With the need to reduce footfall in the department along with other the necessary safety measures, came much of the impetus to enact change within CE too, changes to the workflow, changes to the use of space and effectively a remodelling of the CE technical department overall.

The moves

Our admin team (yellow line in Figure 1) were the first to move, going to the front of house and swapping with the technical inspectors and apprentices.Our decon room also moved (green line in Figure 1), repurposing an office space and adjacent store into a 24/7 swipe-access drop-off zone for clinical staff and removing the need for equipment to be dropped of at the MEL, where decon facilities do not exist. The room also came with an inspection area, cleaning areas and a deep cleaning area.

This decon room and drop-off changed the flow of equipment in the entire hospital, and was followed up with trust-wide communications and involvement of infection control and medical device training. Now only large items such as beds, mobile gantries and bariatric chairs go direct to MEL – all other items come through CE for processing.

Our commissioning store (blue line in Figure 1), that under the weight of new devices, large-scale project replacement programmes and other general needs, needed more of a defined space, swapped places with one of our teams that moved to the large workshop, sharing the facilities with their colleagues from another team.

The improvements

Prior to these moves, each team in a distinct geographical location had their own outgoing shelving for completed works, and devices were collected either by clinical users or technical staff as and when, resulting in delays post-repair to clinical use. With the need to move a team came the opportunity for a redesign of outgoing work, and a collocation of all teams' completions to a singular rack, differentiated by hospital floor. Returns of equipment were then performed by our apprentices daily, and by technical inspectors and technicians as needed, increasing our return rate from 48% same day to 76% same day for all devices, with a new average post-repair/service delay of 1.3 days from technician to return to point of use.

Equipment flow now ensures all portable medical devices come to the 24/7 drop-off, where colour-coded Linbins can help identify the clinical risk of the supplying area. On completion of works from the teams, devices are deposited on the collocated outgoing workshelves before further distribution around the trust. This flow of devices has proven to remove occurrences where the workflow direction went back and forth in some areas. It also increases the visibility of productivity and measurably improves the turnaround times of devices to the betterment of patient care in the trust and other customers.

The changes involved minimal costs (people/furniture moves only) and has aided the reimagining and remodelling the workflow of devices and visitors. It has led to some measurable improvements in overall turnaround times of medical devices and helped create opportunities for departmental growth through the creation of new roles, sharing skills and building resilience.

Stephen Bond *is Principal Engineer and Deputy Head of Clinical Engineering at University Hospitals Plymouth NHS Trust.*

CLINICAL COMPUTING

For safety and efficiency

Paul Roxby, **Jonathan Hughes** and **Stephen Tozer-Loft** outline projects to check treatment instructions are being followed and help doctors know what to do next.

Computing in medical physics and engineering is perhaps most exciting when enabling new diagnostic tests and treatment techniques. It can still be rewarding when used to improve safety and efficiency. This article describes two projects undertaken by the computing section of Radiotherapy Physics at Sheffield. The first helps ensure that instructions on how to treat a patient are for the correct patient when moving from paper to electronic documentation. The second helps doctors know what needs doing next.

A large flatscreen monitor was installed in each radiotherapy treatment machine (linac) bunker, and a keyboard and mouse mounted on an extendable arm nearby (Figure 1). These were connected as a duplicate screen, and as a second keyboard and mouse, to a new computer in each linac control area. This computer runs the oncology information system (OIS) – Varian's Aria in this case.

Project 1: Linac patient monitor

It is vital in radiotherapy that patients are positioned for treatment in the same way as they were at the CT scan used to design their radiotherapy plan. This plan includes the geometrical arrangement of radiation beams and is sent electronically to the linac.

The positioning instructions used to be written on paper forms at CT and later transcribed onto a paper summary of the radiotherapy plan, carried into the linac bunker.

With the new system, the patient is selected on the computer running the OIS, and set-up information is displayed inside the room (Figure 2).

If a patient needs to hold their breath at a certain level – common for left-sided breast radiotherapy to reduce the dose to the heart – the correct patient needs to be selected on a separate computer system that monitors the patient's breathing trace. That system does this using a camera and with a reflective block lying on the patient. It is called RPM (Real-time Position Management, from Varian) and used with Varian Clinac linacs. More recent linacs

IMAGE: SHUTTERSTOCK

> **FEEDBACK HAS BEEN POSITIVE, PARTICULARLY FROM THOSE WHO HAVE WORKED AT OTHER CENTRES**

have breathing monitoring integrated.

There are established checks in place to make sure that the patient selected on the linac is the patient physically being treated. But how do we know that the same patient is selected on the additional computer systems? If not, an incorrect treatment may be given, a scenario highlighted in the Care Quality Commission's IRMER report of 2018/19. In a busy clinic/department it is possible for manual checks that the same patient is selected on all systems to fail.

The solution was the Linac Patient Monitor, as shown in Figure ❸. It runs on the additional computer systems in a corner of the screen and shows whether the patient selected on each system matches the patient selected on the linac. It either covers a blank area of the screen with RPM or additional patient information, which we would prefer not to have on display in the treatment room. Colours are green when the patient matches, pale blue or yellow if no patient is selected, and red if there is a mismatch. A check is made every 10 seconds and a countdown timer shown, in case the software were ever to become frozen.

The system gives an additional layer of safety over manual checks. It can be seen both in the linac console area (Figure ❹) and inside the room (Figure ❷).

With Microsoft Windows it is possible for one program to read the title of another program's windows. This works even for software run via Citrix. In the case of RPM, only the main window title is available, and this contains the patient's first and last name and the date of their reference breathing trace (from the treatment planning CT), but not their patient ID. However, this is sufficient information to identify the patient as the program displays a warning if two patients with the same name were scanned on the same day.

Although it is a normal PC running Windows behind a firewall, RPM is classed as a medical device. The very small risks from running an additional lightweight piece of software on RPM were compared to the real and known risk of patients being treated using the wrong patient's breathing trace. RPM is subject to regular quality control checks and no issues have been seen.

Sometimes in computing, large unanticipated problems are encountered. The Linac Patient Monitor was written to use the OIS database to know which patient is selected at a linac. But a database problem meant this doesn't work if a patient is treated on a different linac to the one booked, which is a common occurrence. The database only shows when the treatment is complete. Fortunately there is an additional log file called the HIPAA log, named after the US Health Insurance Portability and Accountability Act. This records who is working with each patient. Some additional software was written which runs on the OIS server and monitors that log file. It answers questions over the network asking which patient was last opened on a particular linac. The Linac Patient Monitor software now has the information it needs.

Feedback from radiographers has been positive, particularly from those who have worked at other centres. At Sheffield it is regarded as an essential piece of software to facilitate paperless working.

Project 2: Doctors' dashboard

The second development is a zero-click dashboard for oncologists, to show them what work they have to do and which items are the most urgent. This information is stored in the OIS but with Aria it isn't always easy to appreciate. The tasks shown depend on the filters and date ranges selected and items of work can be missed. Chasing people for missing items

Figure ❶ Screen, keyboard and mouse inside linac bunker

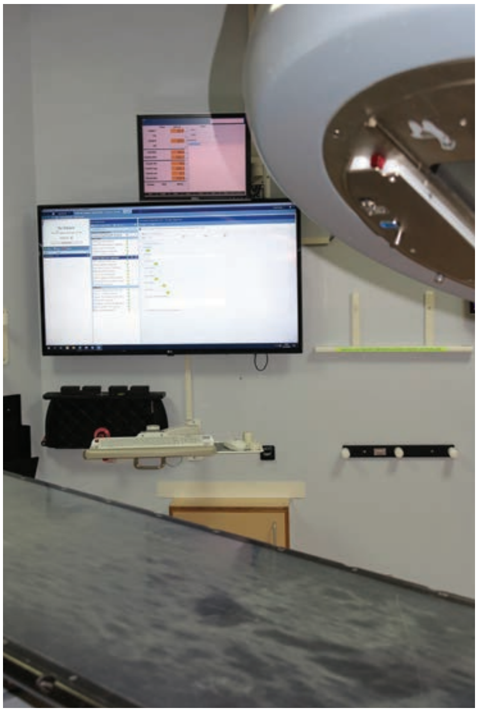


Figure ❷ Set-up information in the Oncology Information System

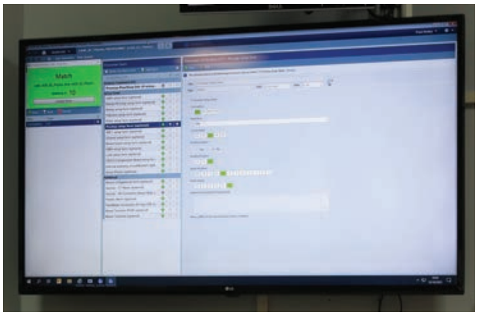


Figure ❸ Linac Patient Monitor showing a match

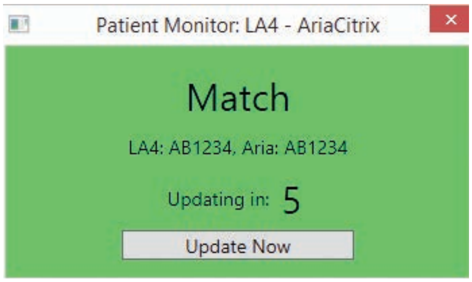


Figure ❹ Linac control area with OIS, RPM and 4D Treatment Console

Figure ❺ Tasks in the Oncology Information System. CT Plan is for a doctor to draw target volumes

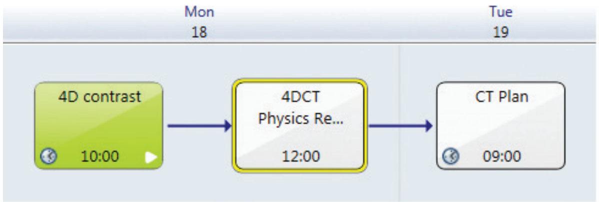


Figure ❻ A mock-up of what the doctors' task list could look like

(This mock up has OSD in the lung group for illustrative purposes. J Trial and J 4DCT are entries from two categories in the Journal)

My work

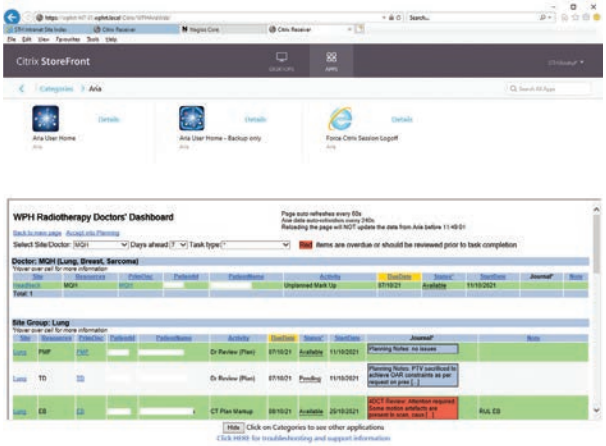
	Site		Item	PrimOnc	Pat ID	Name	Due	Start Date	Note	J Trial	J 4DCT	Last Note
avail	Prostate		PlanReview	OSD	123456	Evans	14-Dec	16-Dec		Pivotal Boost		Struggled to meet rectal constraints
avail	Bladder		Markup	OSD	234567	Archer	14 Dec	28 Dec				
pending	Lung		Markup	OSD	345678	Thatcher	15-Dec	28-Dec			OK	
pending	Prostate		PlanReview	OSD	456789	Smith	20-Dec	24-Dec				

My site groups

Lung	Site		Item	PrimOnc	Pat ID	Name	Due	Start Date	Note	J Trial	J 4DCT	
avail	Lung		PlanReview	CEL	567890	Falconer	13 Dec	18 Dec			OK	RUL - bilateral mediastinum - CEL
avail	Lung		PlanReview	TD	112233	de Lord	14-Dec	19-Dec		CASPER		
avail	Lung	SABR	Markup	MQH	223344	Baker	14-Dec	28-Dec			See below	LUL - SABR - MQH
			4DCT - Inaccurate on inhale phases for sup half of tumour - see journal									
in prog	Lung		Markup	TD	334455	Tanner	15-Dec	28-Dec				
avail	Lung		PlanReview	CEL	445566	Cook	17-Dec	21-Dec				V20 only just met
pending	Lung		Markup	TD	556677	Thomas	18-Dec	03-Jan				

Urology	Site		Item	PrimOnc	Pat ID	Name	Due	Start Date	Note	J Trial	J 4DCT	
avail	Prostate		PlanReview	CJF	889900	Johnson	14-Dec	18-Dec				
avail	Bladder		Markup	MYA	111222	Light	16-Dec	28-Dec		Pivotal Boost		
in prog	Prostate		Markup	MYA	222333	Choir	17-Dec	28-Dec				
avail	Prostate		PlanReview	CJF	333444	Drummer	18-Dec	23-Dec				PTV71 compromised for bowel
avail	Bladder		PlanReview	JT	444555	Pilcher	19-Dec	23-Dec				
pending	Prostate		PlanReview	CJF	666777	Seale	20 Dec	26 Dec				

Figure ❼ Doctors' dashboard, shown below the icons to start the OIS



takes up time and can lead to work being performed at the last minute, which carries risks.

Computing doesn't have the grandeur of architecture, but sometimes the same principles apply – given a problem, some background and some components, it's possible to have a vision for what a solution would look like, and then create it.

The problem: Where there is a lot of face-to-face contact between dosimetrists working in treatment planning and oncologists, communication is easy and people know what needs doing. With remote working, and doctors working in teams for tumour sites, such as lung or head and neck, it is less easy to keep in touch and people may not realise which tasks are the most urgent. Email works to some extent but is separate from the OIS. Unless the whole team is emailed about every issue, information can be missed. This was particularly the case for doctors drawing target volumes on 4D CT scans, which are first reviewed by physicists following the pathway shown in Figure ❺.

Background: A view for each doctor with one line per task, showing them what they needed to do next, was part of the CASS open source system for job tracking in radiotherapy physics written by the author and used in Bristol for many years. At Sheffield, tasks are located in the OIS rather than a separate system but can be retrieved from the OIS database. Doctors have to log in to a web page (generated by Citrix StoreFront software) to access an icon to start the OIS.

Vision: Given that it is known who logged in to the Citrix web page, it should be possible to check whether they are a doctor, and if so, to create a list of tasks for them and for the site groups (lung, urology, and so on) of which they are a member. This would be displayed alongside the icon for the OIS. It would be a zero-click solution – the doctor would not have to do anything extra.

An illustration of what this could look like was created and is shown in Figure ❻.

Components: The Citrix Store front software uses some JavaScript code which is designed to be customised. Sheffield already had an in-house Carepaths Dashboard webpage that retrieves tasks for radiotherapy plan checking from the OIS.

Creating the solution: The Carepaths Dashboard was extended to provide a view for doctors. Entries with particular categories from the journal in the OIS were picked out. Hovering over them with the mouse would display the entries in full. The database query to acquire all the relevant information for the dashboard can take over 10 seconds to run. This is too slow for doctors to wait, so a scheduled task runs every minute and regularly refreshes the data. The Citrix Storefront Javascript file was customised to check if a user was a doctor and if so to include the dashboard in an embedded 'iframe' (Figure ❼).

Training: The new system was presented at a clinical governance meeting. It was well received, and use was allowed straight away, supported by training presentations on a website and training via Microsoft Teams, including for registrars. Every member of the lung team was required to watch a presentation before the results of 4D CT reviews were moved to the new system. The new system is well liked and helps with communication of important information. ■

Paul Roxby, Jonathan Hughes *and* **Stephen Tozer-Loft** *work in Radiotherapy Physics at Weston Park Cancer Centre, Sheffield Teaching Hospitals NHS Foundation Trust.* *The authors would like to thank dosimetrists, radiographers, physicists and doctors who helped with evaluation, feedback and suggestions.*

HOW TO...

Build an effective online quality assurance system

Amy Oana, a Pre-Registration Clinical Scientist, on the process of installing a new quality assurance system and the lessons learned.


IMAGE: SHUTTERSTOCK

In NHS Tayside, radiographic quality assurance (QA) is carried out in accordance with IPEM Report 91. Radiographers carry out Level A QA monthly, the results of which are recorded on paper and later transferred to a spreadsheet. In busy clinical departments, it can be difficult for radiographers to immediately enter the results into the spreadsheet, which delays its accessibility to radiology management and physics.

To make the recording of QA results easier for the radiographers and to make the data accessible to radiology management and physics in real time, a web platform was designed for the direct entry of QA results. The web platform built for this new QA system was developed using Django – a free, open-source web framework in Python – with Semantic UI styling for the front-end design. Among other features allowing for easier development, Django has an in-built method for handling user credentials and authentication, meaning areas of the site and the data stored there is secure. The platform is hosted through Amazon Web Services (AWS), which provides implicit security against any external attacks as default, and the site itself also has https integration verified by Google.

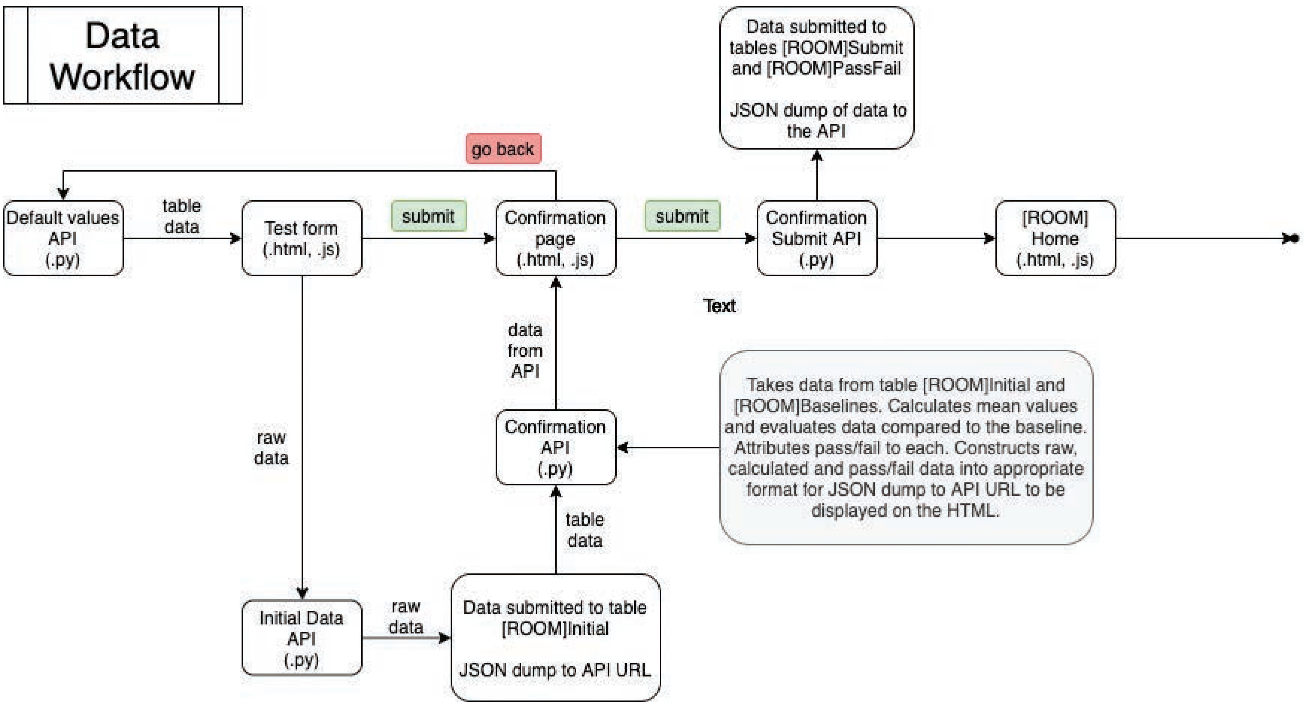
All data stored through use of the platform is stored in a SQLite database. This is backed up to storage in AWS daily to ensure that if anything were to happen to the platform, there would be minimal data loss. The data workflow is shown in Figure 1.

Comparing with baselines

The main function of the platform is to allow Level A QA testing data to be entered into the database and compared with baselines. Each radiographic room has its own user login, for example "nwroomc" which corresponds to Ninewells Room C. By logging in with the credentials for a room, the form for filling in test results is displayed and indicates the baselines for each test above the appropriate fields, as well as a collapsible box detailing the setup instructions and exposure settings for that test (Figure 2). This form is optimised for mobile and tablet to allow for portable use, but can also be used on a computer. The user login acts as the prefix for table names in the database to ensure a simpler way to store the data in the correct location.

All fields in the form are required, as they are all part of the test protocol, with the

Figure ❶ The data workflow for QA data entry. The platform uses a series of application programming interfaces (APIs) to handle the data and display in HTML format.



exception of an optional comment box. This comment box allows radiographers to add additional information of relevance to the testing, for example any issues they encountered with setup which may affect results, or if the QA was carried out following a service. Once the fields are complete, the user can submit the form. If there are any mandatory fields left empty, or expected numerical inputs are not numerical, an error message appears to let the radiographer know what the issue is and which field it applies to so it can be rectified (Figure ❸). Once errors have been resolved, the form can then be submitted.

When the form is submitted, the most recent baselines for that room are applied to the data to determine whether the individual tests and the QA as a whole have passed or failed. A page is displayed to show the submitted results, with the entry green if the test passed, or red if the test failed. In the case of a failed result, a box is displayed underneath showing setup parameters to check, such as tube height and generator density function, to ensure the fail is not a result of incorrect setup. If the radiographer wants to repeat the test, there is an option to go back to the previous form, where all results are stored in the fields for two hours to ensure all tests do not need to be repeated. Once the radiographer is satisfied that the results are a reflection of the performance of the unit, the results can be submitted, and the final table in the database is populated. Graphs of Automatic Exposure Control (AEC) trends are displayed on the post-submission page to allow for better visualisation of how the QA results match recent testing.

> " RADIOGRAPHERS ARE VERY POSITIVE ABOUT THE CHANGES AND THE ADVANTAGES OF USING AN ONLINE SYSTEM

Selecting rooms

The web platform has different home pages for staff groups. Whereas radiographers login as a room for direct data entry, the home page for radiology management shows a dashboard for all rooms which gives a clear overview of the QA status. For each room, it displays the date of the last test, how many days have elapsed since then, and whether the QA passed or failed, with a green thumbs up for 'pass' and red thumbs down for 'fail'. The number of days elapsed is green when within a month, yellow within two months, and red when outside the two-month range. These visual indicators allow for quick comprehension of the information displayed, which is of particular importance as the platform scales to include multiple rooms.

Selecting an individual room from the dashboard also allows radiology management to view the last 10 QA results. This allows them to see whether the QA has been consistently performed, whether it is repeatedly failing, if a result appears anomalous, or if there has been a gradual trend towards the tolerance. The comments are also displayed here, which allows a quick check of post-service results or checking for any issues radiographers have been having. From this page, the AEC trend graphs can also be viewed to give a visual overview of those results.

For physics, the home page has the same functionality as the radiology management section, with an additional function to add baselines. This presents the physics user with a form to input the test results carried out to set the baselines, and on submission applies the IPEM Report 91 tolerances to the data and stores these in the appropriate database table. These baselines automatically update in the data entry form when next used, so the most up-to-date baselines are always visible for radiographers.

This new QA workflow brings benefits to all staff groups involved in the QA system. Data entry is faster for the radiographer, with immediate feedback on results and suggestions in the event of a failed result. For radiology management, having an overview of the QA across all the units makes it easier for them to assist radiographers where issues with QA arise. For physics, having direct and immediate access to the results of QA testing allows for targeted interventions and better planning of the Level B QA programme. It also allows for easier access to records when providing remote assistance to radiographer colleagues, and for a check of all QA results prior to audit.

Positives and negatives

The workflow has only recently been adopted, but radiographers are very positive about the changes being made and the advantages of using an online system. Radiology management are also very enthusiastic about having a dashboard overview, as it makes it easier for them to assist staff.

A large challenge associated with implementing this workflow is the Wi-Fi infrastructure. Wi-Fi is readily available in some areas, allowing the use of a mobile phone or tablet as designed. For some radiographic rooms, particularly those in satellite sites, the platform needs to be used on a computer, which removes some of the portable functionality, such as having the protocol in the room without requiring a paper copy.

Deploying the platform online required a number of steps to ensure the appropriate packages and code structures were in place to run the platform continuously. Part of this also involved introducing functionality to sync the code hosted by AWS with any changes made as part of development. This includes the addition of radiographic rooms, as well as any fixes when errors are raised or improvements based on user feedback. Fortunately, a local software engineer was willing to assist with this implementation, which will allow the platform to grow as the workflow is rolled out across NHS Tayside.

This project is continually evolving as we look to keep improving the workflow for all staff involved in the QA process. The next steps are to continue to roll out this platform across all radiographic rooms in NHS Tayside, with a view to expanding across other imaging modalities in future.

Amy Oana *is a Pre-Registration Clinical Scientist working in Medical Physics at Ninewells Hospital, Dundee.*

Figure 2 An example of baselines and collapsible box with setup instructions for the image uniformity QA test.

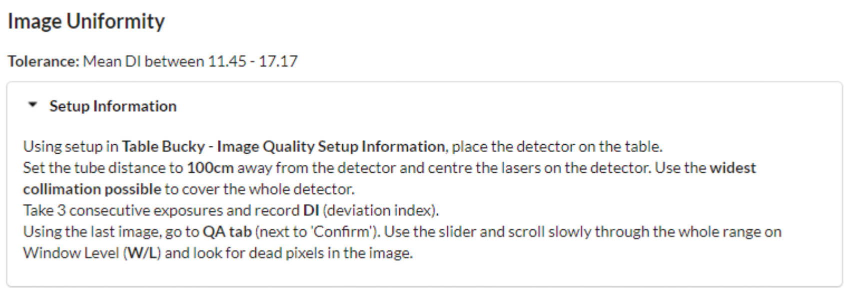
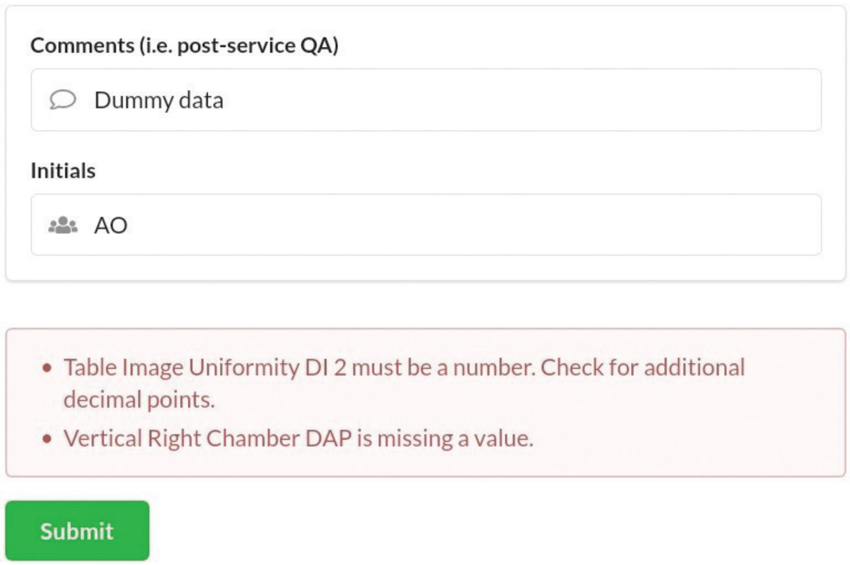
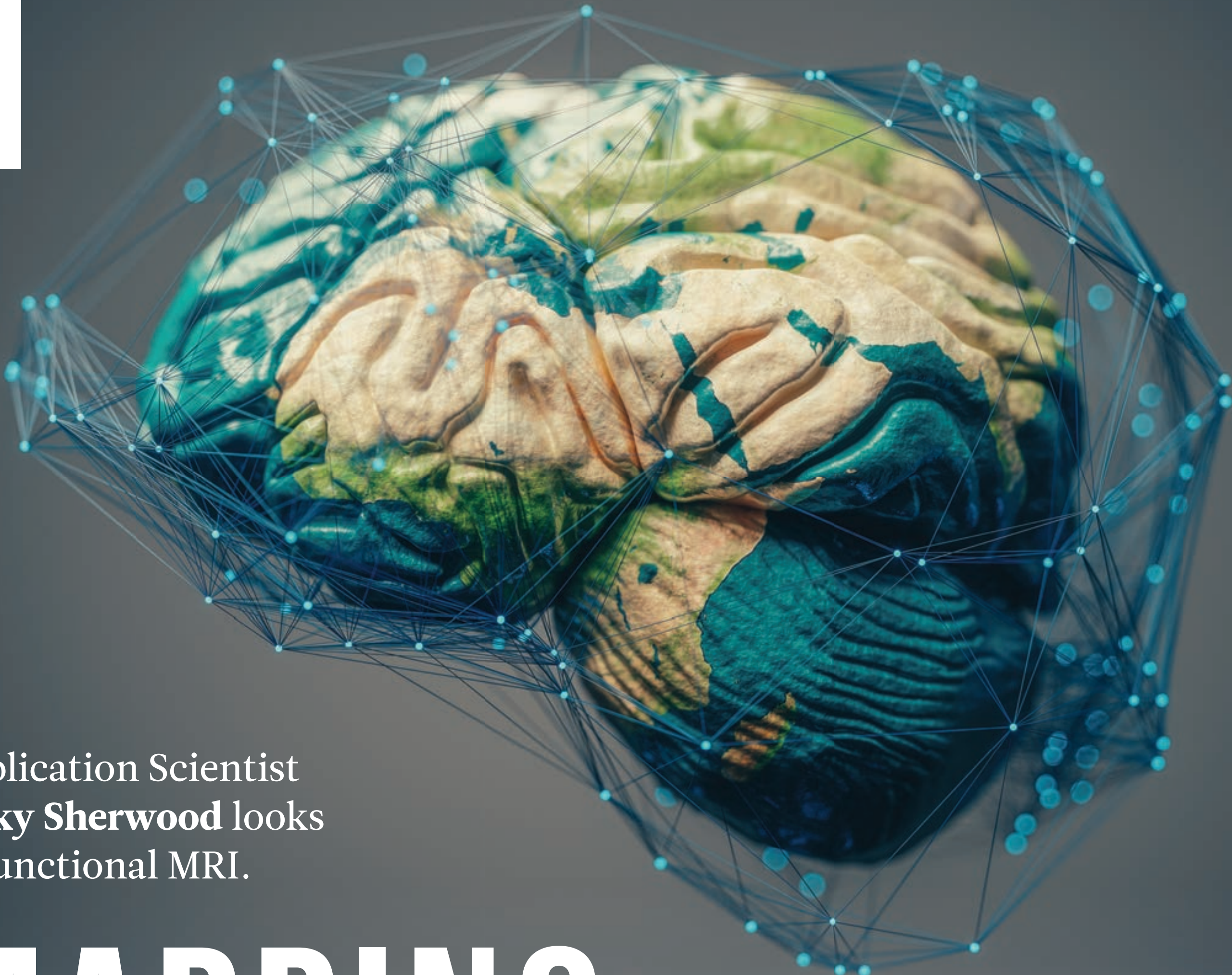


Figure 3 Comment box and examples of the types of error message which display. Each error message states which field the error is attributed to; this allows the radiographer to find it more easily.



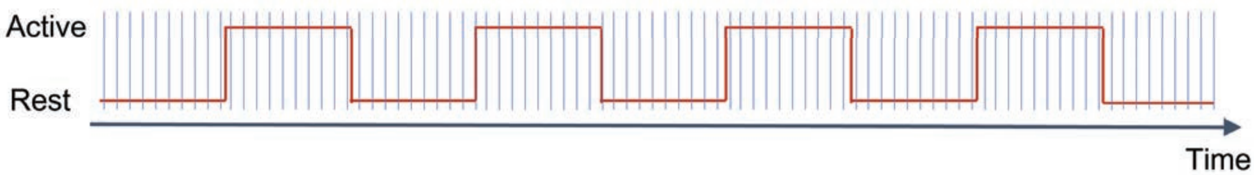


Application Scientist **Vicky Sherwood** looks at functional MRI.

MAPPING THE MIND WITH MRI

Many patients referred for neurological assessment will undergo a magnetic resonance imaging (MRI) scan. In specialist centres, patients requiring surgical intervention may undergo an additional functional MRI (fMRI) exam to map the eloquent cortex relative to the pathology. For a brain tumour, the surgeon would ideally resect the entire tumour with sufficient margin to encompass microscopic spread. Clinically the patient may then be free of cancer, but for tumours

Figure ❶ Paradigm block design for BOLD fMRI. Image slices covering the whole brain are acquired every 2-3 seconds, represented by the vertical blue lines. The state of the brain (active or rest) is indicated by the red line. Activity is achieved by instructing the patient to complete a task (typically motor/language) during the active blocks.



close to eloquent areas of the brain, there could be severe debilitating effects. It can be valuable to visualise areas corresponding to motor and language functions using fMRI to aid in planning the surgical approach.

How do we image brain function using MRI?

fMRI relies on the blood oxygen level dependent (BOLD) effect. In response to a stimulus, bloodflow to specific brain regions increases, resulting in an increased signal in T2* weighted images. Whole brain volumes are acquired rapidly over the course of a few minutes, while stimuli are provided through an experimental paradigm (Figure ❶).

The patient may be asked to tap their fingers, or instructed to think of as many words as possible which start with a given letter, or they may be given a series of words and asked to think of the opposite, for example. This would be done in blocks of, say, 20 to 30 seconds, interleaved with periods of rest. MR signals are plotted voxelwise as a function of time (Figure ❷).

The paradigm design is then used to create a model of the expected signal by taking into account the haemodynamic response, and the image data are compared with this model. Within the primary motor area, the signal time course may agree well with the model from a finger-tapping experiment (following some additional pre-processing steps), and the voxel may be considered significantly likely to lie within a part of the brain responsible for finger movement. Calculated T-statistics quantify the likelihood of this.

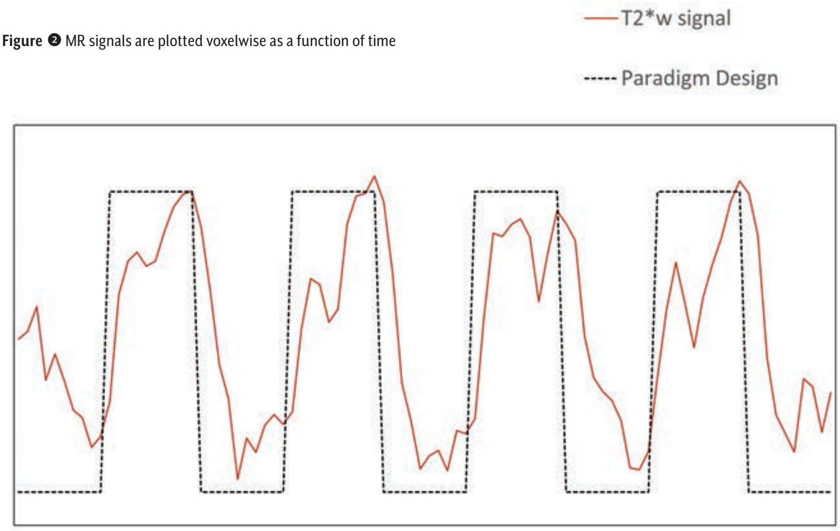
The output is a T-map for each paradigm (Figure ❸), which will be thresholded to best display the area of interest while excluding unwanted areas of noise. It is prudent to run multiple scans using different paradigms, particularly for language areas with less intense activation. T-maps from different paradigms can be overlaid to increase confidence in the result.

The patient experience

Picture this. You have been asked to lie on an MR scanner couch. Someone gives you some earplugs, and then they place a cage over your head which comes surprisingly

IMAGE: GETTY

Figure ❷ MR signals are plotted voxelwise as a function of time



close to your nose. Suddenly the table moves and you're going into a tunnel where all you can see is white plastic above you. A horrific noise starts, which gives you the impression that not only are your earplugs faulty, but that something inside the machine is trying to get out! Some time later you hear a voice asking you to think of as many words as you can that begin with the letter X. "Right, xylophone… X-ray… oh no! Umm, Xerox? Is that American? Does it matter? Hang on a minute, can they tell what I'm thinking? Am I finished yet? I hope they're not checking my answers! Maybe if I crane my neck, I can see something other than this white plastic…"

This is not an ideal experience. But there are many things that can be done with a few key accessories and some extra patient care.

Patient preparation

Patient motion has a huge impact on image quality. The head should ideally be kept still to within ~1mm throughout the exam. This is important for BOLD analysis, but also for coregistration of functional with structural data (as in Figure ❸), which is crucial for reporting of the T-maps. Padding can be used on either side of the head, but simply making the patient feel comfortable and prepared, reducing anxiety and apprehension, can play a huge part in obtaining motion-free data.

"PATIENT MOTION HAS A HUGE IMPACT ON IMAGE QUALITY

Preparation takes time, and often this is overlooked in haste. Giving the patient time to become familiar with the environment, explaining the tasks thoroughly in advance and rehearsing them on a laptop are valuable processes. The operator can then also assess the ability of the patient to complete the tasks. Unexpected issues with vision, comprehension or compromised function can be identified, and the tasks adjusted to the patient, for example by changing font sizes, using simpler language tasks, or deciding on more manageable movements. These processes make the patient feel more at ease, and enable them to fully participate to the best of their ability.

The technology

There are a number of practicalities to address, not least how to instruct the patient during the scan. This could be done manually using voice commands, but the timing of brain activation relative to data acquisition is key, not to mention the sheer concentration required to issue commands repeatably and accurately every 30 seconds. The ideal solution is an automated visual aid, which may be accompanied by an audible cue, and which is synchronised with the timing of the scan.

Today there are a number of off-the-shelf accessories for fMRI. The most versatile solution for visual stimulation is an MR compatible LCD monitor (Figure ❹A), which can be viewed via a mirror mounted to the head coil. This can also be used more broadly for entertainment, thus reducing anxiety and movement in the scanner. Scanners can be configured to generate a trigger pulse at the start of an acquisition. A synchronisation device (Figure ❹B) takes in this signal, and can pass it to a PC via USB connection, for example. This is then used to commence stimulus presentation via one of a number of available software platforms. In this way the operator can be sure that the patient is performing the activity at the right times during the experiment.

In some cases, it can be difficult to assess the engagement of the patient with the task, and so it can be helpful to ask the patient to respond in some way. Fibre-optic response collection devices are available in the form of button boxes, joysticks or handles (Figure ❹C), allowing the patient to participate more fully. For example, there could be a task where the patient is asked to decide whether pairs of words rhyme. This should be done silently in their head; however, an additional instruction could be to press a button if the words rhyme. Correct or incorrect answers are of no real consequence, provided the task is being attempted, so here the response device is used more to maintain the attention of the patient. For more advanced applications it may be necessary to collect the responses and use them as part of the analysis.

For more advanced research use requiring 3D display or virtual reality, or a more immersive experience, MR-compatible goggles are available. It is also possible to observe the patient's response by tracking eye movements using cameras within the magnet bore, either separately from or integrated into goggles (Figure ❹D).

Figure ❸ T-map (colour) created through voxelwise analysis of data from a right hand finger tapping experiment, overlain onto a 3D T1-weighted structural dataset

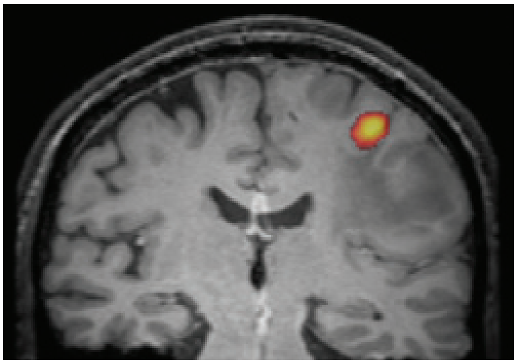
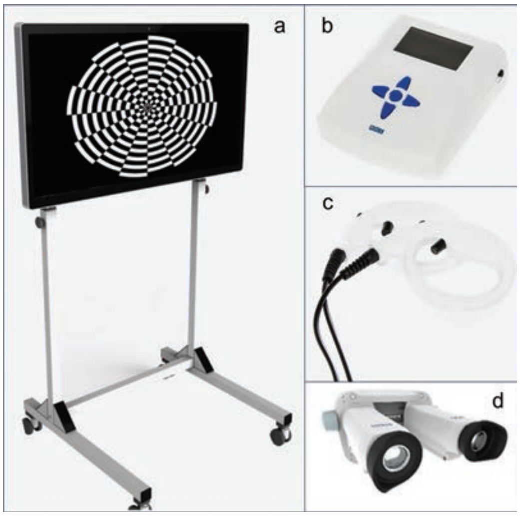


Figure ❹ MR-compatible LCD monitor and accessories



Barriers to adoption

The success of an fMRI service is dependent on a multidisciplinary team of stakeholders. Demand often comes from the neurosurgeon, whose job is to use and feed back on the results. Without a clear vision of the effect on patient care, there will be little justification for it.

The practicalities of setting up equipment and acquiring data can be cumbersome, which can cause lack of confidence in radiographers. Support is key, whether this is in-house or provided by equipment vendors. An all-in-one stimulation and response collection system can greatly help with confidence, and can maximise the chance of acquiring reliable data. There is enormous variation in the specific paradigms used in clinical settings, depending on the software used or the personnel involved. For sites where the service has grown from a research programme, for example, "historic" paradigms might be used simply due to familiarity. There is scant evidence-based literature on this topic, but it is only through consistency in stimulus presentation that fMRI can become consistent and repeatable. Adding this to the inherent variability between patients can lead to a lack of confidence in the results, and therefore an under-utilised service.

Involvement of motivated neuroradiologists is essential. The time spent on analysing and reporting fMRI exams is greater than for a standard MRI. Initially there is a steep learning curve which can seem insurmountable, especially at a time when backlogs are at their worst.

Solutions

To overcome these barriers, there is a role for the physicist. When selecting equipment and software, and when training staff on best practice, physics support can be valuable. There is some misconception that physics support is fundamental to fMRI, however. With the products on the market today and the support available from equipment manufacturers, it is no longer necessary for physicists to take responsibility for data acquisition and processing. Ideally fMRI would be readily available in smaller hospitals without dedicated physics support. Provided the available tools promote consistency, fMRI can be used more widely in precision medicine to ensure the best possible patient care.

Vicky Sherwood *is an Application Scientist at NordicNeuroLab AS in Bergen, Norway. References can be requested from rob.dabrowski@redactive.co.uk*

THE WINNERS ARE…

Gold Medal and Early Career awards have been presented to IPEM members who have made outstanding contributions in their field of work.

Academic Gold Medal and Early Career awards

Academic Gold Medal

Professor Indra Das is Vice Chair, Professor and Director of Medical Physics at Northwestern University Feinberg School of Medicine in Chicago.

An IPEM Fellow, Professor Das is an internationally known medical physicist with a track record of sustained presence in clinical areas, teaching, service and research.

Academic Early Career award

Dr Peter Charlton is a British Heart Foundation Research Fellow in the Department of Health and Primary Care at the University of Cambridge. He has built an international reputation as a biomedical engineering researcher specialising in signal processing for wearables.

President's Gold Medals for Exceptional Service

Claire Hardiman

IPEM Fellow Claire Hardiman is Head of Radiation Physics and Radiobiology at Imperial College Healthcare NHS Trust in London.

She said: "I am delighted and honoured to accept the IPEM President's Gold Medal for Exceptional Service. I was first inspired to volunteer with IPEM at a lunchtime meeting at MPEC nearly 20 years ago, aimed at getting more female members involved."

Dr Viv Cosgrove

Dr Viv Cosgrove is Head of Radiotherapy Physics at the Leeds Teaching Hospitals NHS Trust.

He said: "I was surprised and delighted to receive the President's Gold Medal for Exceptional Service. It was unexpected and flattering, as the work I have been involved in with IPEM has always been alongside very talented and hardworking physicists, engineers and technologists who deserve equal recognition and praise for the work they do for the IPEM membership."

Professor Azzam Taktak

IPEM Fellow Professor Azzam Taktak is Consultant Clinical Scientist and Honorary Professor at Liverpool University Hospitals NHS Trust.

He said: "I am extremely flattered and honoured to be awarded the Gold Medal for Exceptional Service. Over the last 20 years, I have joined many IPEM committees and served a number of offices, most notably being CEng Registrar between 2008 and 2012 and Vice President for Engineering between 2012 and 2015."

President's Gold Medals for Exceptional Service during the COVID pandemic

Dr Richard Axell

Dr Axell is Principal Clinical Scientist at University College London Hospitals NHS Foundation Trust.

He volunteered to work within the Nightingale Hospital in the ExCeL Centre in London to assist with the many pieces of medical equipment in use. Not only was he volunteering to work within a highly demanding environment, but he was also challenging himself by working outside of his usual field of urodynamics.

Morriston Hospital Medical Device Training Team

The team at Swansea Bay University Health Board designed, developed and delivered three significant pieces of work with considerable impact on improving patient care and demonstrating excellence and leadership during the COVID pandemic.

Southeast Mobility and Rehabilitation Technology Centre Healthcare Science, Edinburgh

The team led the design, manufacture and distribution of face visors during the PPE shortages at the start of the pandemic for NHS Lothian and the Edinburgh Health and Social Care Partnership. Some 34,000 visors were produced in the first eight weeks.

Non-Ionising Radiation Team, Department of Radiology, Medical Physics and Clinical Engineering, University Hospital of Wales

The team developed new referral pathways, responding to increased demand in spite of the constraints of the pandemic. They demonstrated hard work, flexibility, resilience and performance of the highest standard throughout the pandemic.

BOOK PITCH

Physics and medicine partnership: from ancient to present time

Ihsan Al-Affan and **Abdul Kadir Ismail** outline the ideas behind and the content within their new book.

The purpose of this book is to provide a greater understanding of the historical relationship between physics and medicine over the last 5000 years, as developed and maintained by various civilisations around the world.

We selected key topics and considered how they demonstrate the influence of physics on various aspects of life and health, including maintenance, diagnostics and therapy.

We hope that those reading the book can learn something new from it and that it will also contribute to improving practice and healthcare in everyday life.

The book is divided into 10 chapters covering a variety of topics, such as physiotherapy, heat in therapy, acupuncture, hydrotherapy, surgery, art therapy, religion and the supernatural in diagnostic and therapy, medical diagnostic imaging and radiation therapy. Most of the physical methods and their applications to medicine have been widely used in ancient China, India, Japan, Egypt, Rome, Greece, medieval Islamic countries, Mesopotamia, Persia and other ancient cultures and civilisations around the world. Many of these methods are still widely used all over the world for the purpose of maintaining a healthy life, such as a treatment for pain relief, which at the same time reduces anxiety and blood pressure.

With the Renaissance and the invention of electricity, new branches of medical physics in diagnostics were created and numerous diseases have since been treated using medical imaging and radiotherapy. The new branches utilised different types of radiation, such as photons, electrons, protons and neutrons, among others. This period witnessed the emergence of the field of health and medical physics as a recognised discipline where the medical physicists and technologists played an essential role in medical diagnosis and treatment.

The book is mainly aimed at the general public with the hope that it will raise awareness of the importance of medical physics. It is also intended as a historical supplementary textbook for medical or physics courses in academic medical physics graduate programs, as well as a reference book for the general public on the historical influence physics has had on medicine and for those who want to gain a deeper understanding of all topics relating to physics and its applications to medicine. It may also satisfy the curiosity of medical physicists who are interested in reviewing the history of the science underlying their day-to-day clinical activities.

"IT WILL RAISE AWARENESS OF THE IMPORTANCE OF MEDICAL PHYSICS

Physics and medicine have been in close partnership for a very long time, which has served to improve the diagnosis, treatment, and maintenance of human health. Most of the classical methods used by ancient cultures and civilisations proved, in general, to be effective, affordable and had minimum side effects. The great advancements in science and technology in the modern era have been remarkably influenced by the achievements and developments made by scientists and physicians of the ancient civilisations. It may be worthwhile for humanity to start evaluating those ancient physical methods and continue to develop them to keep ahead of the future challenges.

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