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**FIT FOR PURPOSE?**

We are now in the midst of the recruitment process for the second cohort of STP trainees and some 9 months into the rotations for the first cohort. Reviews and revisions of curricula and processes are in process and it seems an opportune time to ask if the MSC programme is fit for purpose.

For the STP programme the implementation of MSC for medical physics and clinical engineering has clearly not provided an improved provision of educational opportunities for this vital component of our workforce. Clear concern remains over the ability of market forces to deliver HEFCE funded training places on vocational degrees. The planned increase in tuition fees may further impact the recruitment of students onto courses and it is clear that those institutions offering courses will only deliver these courses if they have sufficient registrants. The Department of Health is concerned over the risks inherent in sustaining this workforce and in some areas funding is being provided to support a ‘grow your own’ process. This would appear on the surface to be helpful but still requires trainees to attend an approved course of which there are very few. It is imperative that the provision and coverage of suitable courses be urgently addressed. I have asked IPEM Professional and Standards Board to look to devising a training programme which is MSC compliant for the clinical engineering workforce as this appears to be most at risk at the present time. This group is considering a programme which will span the assistant, associate and practitioner grades. Significant work has been undertaken in Scotland to address this issue and I believe we can learn much from their programme. We must all continue to lobby our local planners to ensure this underprovision is not forgotten.

The implementation of the STP programme has rightly led us to review a well-established programme and hopefully to grasp opportunities for improvement. The Institute held a very successful STP and Part I trainee day in York in January which provided an opportunity to gather first-hand information from the trainees. As a Training Officer within an IPEM training consortium the key issues have been in planning a training programme that enables the trainee to undertake the required competencies in the time allowed. The STP programme requires a significantly wider range of expertise in a training consortium than the IPEM Part I training scheme. It also needs access to equipment that may not be available in departments. The need for regular and rapid access to assessor time is impacting upon staff time to the detriment of service commitments. This was an impact that was apparent from the Genetics Pilot and yet was not addressed adequately in the scope and scale of the Medical Physics and Clinical Engineering programmes.

**REVIEW MUST TAKE PLACE**

There are clearly differences in the range and number of competences required in the different rotations and it is vital that these are reviewed if the rotations are retained with equal time commitments. It is recognised that there was little consistency checking between the different rotations due to the fragmented development process. This has been perpetuated in that the specialist rotations are being developed in isolation from the initial rotations. As these programmes are reviewed it is essential that these are considered in a more holistic process that considers the knowledge, understanding and competencies required at all levels of the programme. The MSC programme is not the IPEM scheme compressed into 3 years. Of much more concern to me has been the issue of quality assurance in the programme. The concept that any centre can recruit and train a trainee is a serious flaw in the programme. Understanding the level required for each of the identified competencies has proven difficult and with the trainer often acting as the assessor the system in its current form is not self correcting. There is the potential that we will be unaware of the issues until the final exit exam unless steps are taken to audit the process at regular intervals. It is an urgent requirement that there is an accreditation programme for training centres to secure the quality of output we all desire. I have again asked Professional and Standards Board to review the existing IPEM accreditation scheme so that it can be applied to the STP programme as soon as possible. I hope this can be delivered in conjunction with the National School; however, should this not be possible I would propose to publish the details of IPEM-approved training centres to inform future trainees as they make their choices for training. If we are to secure the resources necessary to deliver the STP programmes it is vital that approved training centres are recognised by their respective Trusts and that local Education and Training Boards appropriately resource these centres.

The Department of Health has now commissioned Royal Colleges to develop the Higher Specialist Scientific Training (HSST) curricula prior to this training being offered to the current workforce in 2013. It is essential that the STP competencies link seamlessly with programmes of Accredited Specialist Expertise and HSST. I firmly believe that the education and development of the scientific workforce does not cease on completion of the STP programme. For the MSC programme to be fit for purpose it must develop the entire workforce over their whole career. It must respond to changes in technology and service requirements with speed and creativity. Our role must be to shape these programmes with vision and ingenuity to ensure that they are fit for purpose.

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Peter Jarritt
President
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By merging a 3T whole body MRI and a cutting-edge PET scanner, you open the door to endless new possibilities.
Radiotherapy treatments may result in missed fractions due to any number of reasons, including machine breakdown, holidays, patient non-compliance and medical complications. Generally, missed fractions are compensated using an array of strategies such as weekend treatments, adding twice daily (BID) fractions, extending treatment times and fractions and increasing the dose per fraction of the remaining fractions. Some of these strategies can have a negative impact on tumour control and are logistically resource intensive. Strategies such as adding weekend or BID fractions provide a good likelihood of restoring the effect of the prescribed radiotherapy treatment because the total dose is still administered in the intended time period with the same dose per fraction.

Clinics may also employ less resource-intensive methods as a form of compensation which are very useful but unfavourable, at least amongst some clinicians, as they require specific knowledge of radiobiological parameters or assumptions about them, which leads to uncertainty about the clinical outcome of the compensation strategy.

The purpose of the work recently published by a researcher from Princess Margaret Hospital, Toronto, Canada (J Med Dosim 2011; 36(4)), was to estimate the biologic effect of radiotherapy fractions independently of radiobiological parameters. An alternate approach was utilised to achieve this – by expressing the limits in biologically effective dose (BED), without assumptions, for very low and very high radiobiological parameter ratios. BED is regarded as a measure of the true biological dose delivered by a particular combination of dose per fraction and total dose to a given tissue characterised by a specific $\alpha/\beta$ ratio. $\alpha/\beta$ is the ratio of ‘intrinsic radiosensitivity’ to ‘repair capability’ of a specified tissue. BED is the quantity by which different fractionation regimens are intercompared.

The paper develops simple BED formulation for the following three missed fraction strategies, in addition to giving worked clinical examples related to each strategy:

1. Increasing the dose per fraction of the remaining fractions,
2. Increasing the number of fractions and the treatment time,
3. Increasing the treatment time but maintaining the dose per fraction.

The first two strategies aim to preserve the tumour BED whilst defining limits on the normal tissue BED. Figure 1 shows the maximum BED and dose per fraction where 0–30 extra fractions are given as a compensation strategy. The third strategy preserves the normal tissue BED. The formulation developed in the paper makes use of the linear quadratic model / BED, relative effectiveness, biologic effect, the tumour growth term and the total dose.

The work shows that it is possible to calculate the maximum effect using simple formulae. The specific strategy that is used depends, to a great extent, on the comfort level and prior experience of the radiation oncologist carrying out the treatment. It is hoped that these limits may be helpful in evaluating the usefulness of the compensation strategy and in guiding clinical decision making.
Effects of obesity on dose received from CT scans

Using a series of computational phantoms, researchers from the Rensselaer Polytechnic Institute in the US have quantified the radiation dose received by obese patients undergoing routine CT scans (Phys Med Biol 57: 2441).

The team derived phantoms representing overweight and obese patients by modifying existing adult male and female phantoms, which comprise more than 100 deformable organs defined using mesh geometry. Differing amounts of subcutaneous and visceral adipose tissue were incorporated to simulate increased body mass indexes (BMI).

Ten phantoms (five male, five female) with BMIs ranging from 23.5 kg/m² to 46.4 kg/m², representing normal weight (NW), overweight (OW), obese level-I (OI), obese level-II (OII) and morbidly obese (MO), were defined in the Monte Carlo N-particle extended (MCNPX) code for organ dose calculations.

The researchers simulated CT scans for all phantoms using a multi-detector CT model. Tube potentials from 80–140 kVp were considered and the results were normalised to 100 mAs.

MCNPX calculations showed that, compared to the normal weight phantom, doses to superficial organs decreased slightly for the higher BMI phantoms, whereas doses to deep organs decreased significantly as the phantom’s BMI increased. These calculations assumed a constant tube potential of 120 kVp and current time of 100 mAs.

However, using constant tube potential and current time values does not represent a realistic clinical scenario. In practice, to maintain diagnostic image quality, the increased photon attenuation experienced in overweight and obese patients must be compensated for by increasing either or both of these values.

For example, tube potential is typically increased to 140 kVp for CT scans of morbidly obese patients. This study showed that increasing the tube potential from 120 kVp to 140 kVp increased organ doses by as much as 56 per cent for organs within the scan field and 62 per cent for those outside it.

Another way to improve image quality is to increase the tube current, for example by doubling the mAs for obese patients. Calculations showed that doubling the tube current (at a constant 120 kVp) increased the effective dose [relative to the normal weight phantom] by 57 per cent, 42 per cent and 23 per cent for obese-I, obese-II and morbidly obese phantoms, respectively.

It is hoped that the obese phantoms created for this study can be used in the future to study image quality and organ doses for optimisation of CT, as well as PET and SPECT.

The ultimate goal of this ongoing work is to include dose data for these obese phantoms in a CT dose reporting software tool called ‘VirtualDose’.

MORE INFORMATION
This story was reported on Medical Physics Web on 11th April. http://medicalphysicsweb.org/cws/article/research/49247

SELF-PROPELLED DEVICE
Researchers at Stanford University have developed an implantable medical device that propels itself through the blood stream to deliver drugs, or perform diagnostics or microsurgery. The key breakthrough was eliminating the need for batteries, instead using a magnetically-coupled coil for power.

A NOVEL GLUCOSE BIOCHIP
Engineers at Brown University have designed a sensor that can check blood sugar levels by measuring glucose concentrations in saliva, eliminating the need for diabetics to draw blood. It is based on plasmonic interferometers – changes in light intensity yields glucose concentration information.

MR SPECTROSCOPY
A new imaging technique for diagnosing brain tumours could preclude the need for surgery in patients with tumours located in areas that are too dangerous for biopsy. MRS provides a definitive diagnosis of cancer, based on imaging of a protein associated with a mutated gene found in 80 per cent of low- and intermediate-grade gliomas. The accuracy predicted by MRS imaging was 100 per cent in a Texas study.

PREDICTING TUMOUR GROWTH
An algorithm developed for weather forecasting can be used to predict the spread of brain tumours, according to a new study from Arizona State University. The researchers state that an accurate forecast system for glioblastoma may prove useful for treatment planning and patient counselling.
The Institute of Nuclear Medicine at University College London Hospital is no stranger to hybrid imaging technology. In 2000, it was one of the first departments in the UK to set up a clinical PET/CT service with great success, currently imaging approximately 100 patients per week. It has now taken on the exciting challenge of being the first to set up a clinical PET/MR, the latest development in hybrid imaging from Siemens in Germany.

Professor Peter Ell provided the UCLH Trustees with an impossible to turn down opportunity to fund this exciting piece of technology, which has just started operation on 2nd April this year. It has been established as an important part of the brand new UCH Macmillan Cancer Centre to provide its patients with an holistic experience where all essential facilities are under one rather spectacular roof (see http://www.uclh.nhs.uk/OurServices/OurHospitals/CC/Pages/Home.aspx for more details).

Anna Barnes, John Dickson and Wendy Waddington (UCL Hospitals NHS Foundation Trust) present the challenges and thrills of commissioning and running the first PET/MR service in the UK, with a new scanner from Siemens.
REQUIREMENTS FOR INSTALLATION

The unrestricted nature of the funding offered will allow the system to be used for clinical and research studies, and for both oncological and non-oncological applications from the outset. Installation of the PET/MR scanner has been not only a first for medical/clinical science in the UK but also a first in terms of its requirements for installation. When the technological developments to support simultaneous PET/MR were first announced by Siemens in 2010 it presented a unique opportunity to install this compact single-gantry system into the Cancer Centre, which was at the time nearing the final detailed stages of its pre-construction design.

Once the funding was confirmed, the challenge was on to reconfigure the previously planned PET/CT unit to take PET/MR and all its associated facilities into the same and therefore limited space. The scanner room floor was strengthened further to take the specified 10 tonne magnet bore and gantry, and the room modified to incorporate an RF cabin with an additional 20 mm of steel sheet magnetic shielding in the wall immediately adjacent to the surgical recovery unit to protect its extensive array of bed-head physiological monitoring equipment.

An extra-long pipe was also needed to vent the 1,000 litres of super-cooled helium in the event of a quench – to run from the scanner on the lower ground floor to the rooftop garden seven floors above. To comply with safety guidance the design also required minimal bends despite having to be routed under, over or around all of the already existing structural columns and beams.

In addition to the retrofit it was the first time in the UK that PET radiation shielding was needed to sit alongside the RF and magnetic shielding. After modelling realistic patterns of use and patient positioning with a number of 18-F and non-18-F PET tracers it was calculated that 5.8 tonnes of lead would be needed to surround the scanner room alone. Special glass had to be made for the viewing window in the control room that provides the radiographers with a
clear view of the patient on the bed since it needed to give protection from both the static field and the penetrating 511 keV gamma radiation emitted from the patient. In addition a specially designed pressurised door was also installed since with approximately 1 tonne of lead it becomes impossible to move manually.

The final logistical difficulty was the requirement to install the gantry into the uncompleted building way back in September 2011, almost 6 months before it was to be used; the final glazed wall panel had to be fitted behind it as it was lowered into place.

Thrice weekly visits by a team of the hospital’s physicists and radiographers, to what was essentially a building site, complete with hard hat and boots, ensured that the core gantry was continually monitored for ambient temperature, cold head compressor function and the partially filled helium level until final system installation, testing and commissioning could begin in January 2012.

OPERATIONAL ISSUES TO BE CONSIDERED

Once the scanner was installed and accepted operational issues had to be considered, such as how the monitoring of radiation dose and contamination were to be performed in the scanning room. Usual methods of radiation monitoring necessarily involve battery-operated devices that are incompatible with the high magnetic fields around an MR scanner. Instead, daily wipe testing of the bed and coils are performed whilst personal
Monitoring is currently performed on a weekly basis using optically stimulated luminescence (OSL) devices, having previously established that their properties are not affected by moving through the static magnetic field. The setup time for a patient is slightly longer than for a routine PET/CT examination since a head coil and three to four body matrix coils need to be positioned on the patient for the purposes of a whole body acquisition. However, throughput will be less and therefore it is expected that the accumulated whole body radiation dose received will be similar to that of a PET/CT radiographer. We’ve also had to reconsider the patient pathway in the department so that appointment times reflect the additional screening time needed to perform the MR safety check for metal in and about the body as well as preparation time for the patients to disrobe fully before being injected.

Of possibly more interest to the physicist, QA procedures necessitate a combination of the usual daily PET detector normalisation alongside weekly SNR and uniformity MR tests that examine both receiving coils and gradient coil integrity. Since the attenuation correction performed on the PET data is calculated from specifically designed MR sequences that map fat and water in the body separately, it is very important to monitor any drift in performance of the MR scanner regularly.

**BENEFITS OF THE SYSTEM TO THE PATIENT**

Although the concept of multimodal fusion of images has been around for a number of years now, the Siemens mMR Biograph is a truly hybrid system providing simultaneous imaging of both PET and MRI. Based on the Siemens 3T Verio model with TIM technology that allows rapid whole body imaging and specially designed coils to minimise photon attenuation, the PET detector rings are fully integrated into the scanner gantry (see figure 1).

The PET camera uses lutetium oxyorthosilicate (LSO) crystals (chosen because the magnetic susceptibility characteristics are similar to human tissue). The critical modification, however, is the use of avalanche photodiodes (APD) in place of the photomultipliers conventionally used in PET and PET/CT systems, as these silicon-based devices used to collect the light signal are unaffected by magnetic fields. There are some compromises to be made when using APDs, typically degraded signal to noise and timing properties, but our own acceptance testing and published results from the Technical University in Munich, Germany, show that it is performing as well as, if not more efficiently than, the standard PET technology.

**FIGURE 1.** Schematic showing position of PET detectors in relation to magnet coils (dark grey) and gradient coils (light grey).
Hybrid imaging has been shown to represent the way forward

The Way Forward

Clearly hybrid imaging has been shown to represent the way forward for medical imaging technology, and the rapid take-up of PET/CT in clinical practice since 2000 has not only ensured that the fused image has become the preferred visualisation tool for both reporter and referrer but has also generated significant cost savings in the manufacturing and subsequent commercial cost of these systems.

An additional critical factor has been that the CT subsystems integrated into these hybrid devices were already mature standalone CT scanners, reducing the cost of the hybrid system and minimising the need for further training of staff groups already experienced in use of the technology. The same will undoubtedly be true of PET/MR.

Worldwide Use

Although the first in the UK, there are already several scanners in Germany and North America, and two more were being installed in Copenhagen and Naples the week that our machine at UCH was being commissioned. It won’t be long before there are more systems in the UK and it proves its value as the first imaging investigation of choice for many indications.

References


PET/MR imaging of a ‘live’ phantom: tested on a celery!

Sofia Michopoulou (UCL Hospitals NHS Foundation Trust)

For the past 6 months I have worked at the Institute of Nuclear Medicine at UCLH as a Part I Trainee Clinical Scientist. In addition to the routine physics work in nuclear medicine I got involved in the commissioning of a new SPECT/CT system and undertook projects in diagnostic imaging and radionuclide therapy. My placement also coincided with the beginning of the PET/MRI service at the new UCH Macmillan Cancer Centre. Although my recent PhD addressed MRI quantification for spinal disease diagnosis, I have not had a clinical placement in non-ionising radiation so this was a great chance for me to experience the commissioning of a PET/MRI system and the introduction of its clinical imaging service.

This article describes a project I carried out aiming to produce PET/MRI data simulating clinical imaging without scanning a person or animal. These data were used for qualitatively evaluating PET to MR image registration in a near-clinical situation. This is in addition to the quantitative evaluation of image registration following the manufacturer’s method.

The first step was to identify a suitable object for imaging: something that would provide sufficient MR signal, can demonstrate some sort of radionuclide distribution and is also MR safe. One approach would be to design a Perspex phantom with radioactive enclosures, but this would lack in anatomical detail. Using a ‘natural’ phantom such as a fruit or vegetable would provide more structural detail for MR imaging (http://insideinsides.blogspot.co.uk).

Researchers in Germany are using PET and MRI modalities to quantitatively study the transport of carbon and water in plants. They developed a small PET scanner and a portable MR cuff specifically for imaging plants. In a similar manner, we decided to water a plant in FDG and image the uptake. For our body-sized scanner a chunky plant was required and it had to be ‘thirsty’ enough to rapidly absorb the FDG before it decays. A colleague suggested imaging a celery, inspired by her children’s school project.

As a feasibility test, food colour was used to water a celery plant and estimate the uptake time and activity required for imaging. We then looked at the radiation protection aspects of work with radioactive... vegetables. After a proof of concept scan on one of the PET/CT scanners at INM we went ahead with the PET/MRI experiment. The head coil was selected for MR imaging to provide high sensitivity. T1 and T2 sequences were acquired to provide anatomical definition; DWI data were obtained to look at the diffusion patterns of water molecules, while the two-point Dixon sequence was also acquired for attenuation correction purposes. A 15-minute PET scan was acquired simultaneously using a single bed position thanks to the larger than usual 25 cm axial length of the PET detector ring.

MR offers an insight into celery anatomy providing visualisation of the vascular bundles (xylem), whilst PET revealed tracer uptake through these veins (figure 1). This information was used for the qualitative assessment of PET to MR registration. The axial images were particularly useful as they depict small structures such as the celery veins through which FDG is transported allowing for visual assessment of PET to MRI matching.

Diffusion-weighted data show that the primary diffusion orientation follows the long axis of the stalks which matches with the radionuclide distribution seen in PET. As expected, there was higher FDG concentration near the plant root, yet some tracer uptake is observed throughout the length of the celery stalks.

A rather surprising feature is the presence of focal ‘lesions’. After a closer look it was noticed that these correspond to the positions of rubber bands used to keep the celery upright in its vase during uptake. It appears that the tension applied traumatised the vascular bundles causing localised leakage thus creating FDG accumulation spots.

In this project, the celery served as a ‘live’ phantom providing a cheap and easy method for qualitative assessment of PET/MR image registration and fusion, whilst also providing some early diffusion and attenuation correction data. In conclusion, I feel that the strengths of MRI as a functional imaging modality – as we have begun to see here – and its versatility make it a great complement to PET for multi-modality imaging. The images produced will be exhibited as artwork in the Cancer Centre.
European Medical Centres Rapidly Adopting New Elekta Beam Shaping Technology for Radiation Therapy

Agility™ multileaf collimator (MLC) promises faster, more conformal treatments for patients with cancer

Twice the leaves
Using twice the number of leaves typical of many standard MLCs, the individual leaves of Agility can travel at twice the speed of those in conventional MLC devices—providing the dual benefit of exquisite beam shaping and shorter treatment times, increasing both patient comfort and the clinic’s therapy delivery efficiency. In addition, by virtue of a new, innovative design, Agility has demonstrated extraordinarily low leaf transmission, reducing the patient’s non-therapeutic radiation exposure.

“Agility enables us to give a high dose of radiotherapy to a smaller anatomical area, and its accuracy helps reduce side effects,” adds Fiona Milnes, radiotherapy services team leader at The James Cook University Hospital, which recently opened an expansion of its radiotherapy services. “Demand for cancer services is increasing all the time and this expansion gives our patients access to the very latest technology in a purpose-built unit that will really raise the profile of James Cook.”

Modern cancer treatment is very complex and will continue to be even more so,” Punszep continues. “It’s vital to be able to shape a radiation beam with high precision to avoid harming surrounding tissue, while maintaining time efficiency. Agility is designed to meet these demands. When Agility enters mainstream use in clinics worldwide, hundreds of thousands of patients will benefit from this unique device every year.”

Agility can be purchased as part of a new radiotherapy solution from Elekta, as well as an upgrade option to a large part of Elekta’s installed base of linear accelerators. This enables clinics to maximize the potential of their existing equipment.

For more information please visit: www.elekta.com/agility

Technology addresses new challenges
Introduction of Agility comes at an opportune time given dramatic increases in cancer incidences in many parts of the world, according to Tomas Punszep, President and CEO of Elekta.

“According to WHO, cancer is a leading cause of death worldwide, and the incidence is expected to continue rising significantly,” he notes. “To meet this increasing need, we have collaborated closely with leading hospitals and research institutions to develop a solution that can increase the throughput of patients while delivering outstanding precision. I’m proud to see that one of our largest projects ever is now ready to contribute to improving cancer care treatment.”

Two medical centres in the United Kingdom are the first to treat patients on radiotherapy systems equipped with Elekta’s new Agility 160 leaf MLC, a device that uses moveable tungsten “leaves” to conform to the shape of a tumor while radiation beams are delivered from different angles around the patient. St. James’s University Hospital (Leeds) and The James Cook University Hospital (Middlesbrough) began treating with Agility in April, setting the stage for additional European hospitals to start Agility aided therapy in the coming weeks. Ahead of these clinical launches, Elekta had announced CE Marking for Agility, enabling medical centres in Europe and other regions to adopt the technology for their patients with cancer.

“This truly represents a radical improvement in the way we deliver radiotherapy, combining both speed and precision in tailoring the radiation beams to the exact shape of the patient’s tumors,” says Vivian Cosgrove, Ph.D., head of radiotherapy physics at St. James’s. “Agility enables a faster delivery of advanced radiotherapy treatments. Reduced treatment times will lead to a better experience for the patient and will improve access to the technology for the benefit of more of our patients.”
The last decade has seen the emergence and rapid clinical implementation of various in-room x-ray based image-guidance systems for radiotherapy. In 2002, the first kilovoltage cone beam CT scanner (kV-CBCT), mounted on a standard linear accelerator, was installed at The Christie Hospital by Elekta.\textsuperscript{1} This research version, later to become the full commercial Synergy\textsuperscript{®} system in 2005, demonstrated that ‘CT like’ images of the patient could be acquired immediately prior to treatment, and compared to the CT scan used for treatment planning. Varian also developed a similar kV-CBCT system called the On-board Imager\textsuperscript{®} (OBI). The images from these systems were sufficient to visualise the internal anatomy for assessment of motion and deformation of the target and neighbouring organs at risk. This enables: on-set correction and quantification of geometrical treatment uncertainties; feedback on the effectiveness of patient immobilisation and preparation, e.g. rectum and bladder fill states; construction of evidence-based...
The integrated linac-CBCT scanner was not the first in-room 3D x-ray imaging system. In-room CT scanners on rails (kV-CT) had used a common couch to transfer patients between a CT scanner and linac in the same room for a number of years previously, but were not widely taken up due to the additional footprint and cost. However, the kV-CBCT market continued to grow rapidly.

In parallel to these developments was the rise of the TomoTherapy® system (now owned by Accuray). This utilised a compact linear accelerator mounted on a CT scanner gantry to irradiate the patient with a spiralling fan beam in much the same geometry as a diagnostic CT scanner (MV-CT). Modulation of the fan beam during rotation allowed complex dose shaping (intensity-modulated radiation therapy (IMRT)) and a lower energy de-tuned version of the beam could be used for imaging via a bank of detectors on the opposite side of the gantry. Finally, megavoltage CBCT (MV-CBCT) became a commercial reality in recent years with the Siemens Artiste® system.

Since the introduction of these different systems (figure 1), a number of reports have been published describing techniques for measuring individual aspects or overall performance, and in one case evaluating systems within a common framework. However, 7 years on from the commercial introduction of kV-CBCT systems and in spite of the widespread adoption of the various IGRT technologies, only a few reviews and guidance reports have been produced by professional bodies. For this reason an IPEM working party was put together in 2011 to provide UK recommendations, specifically on the acceptance, commissioning and quality assurance of in-room 3D x-ray based image-guidance systems.

Their first objective was to perform a survey of UK practice, for those centres with IGRT equipment. A questionnaire consisting of five sections was distributed to all radiotherapy centres in the UK, covering general information about the systems in treatment margins and adaptive planning.
Almost all centres perform daily, weekly and annual quality control on their IGRT systems.

GEOMETRIC ACCURACY

This section was comprised of eight tests used to determine the magnitude of a different source of geometric uncertainty:
1. source and detector position;
2. x-ray collimator position;
3. 2D image scaling;
4. 3D image scaling;
5. imaging treatment isocentre position;
6. matching / table registration accuracy;
7. automatic registration algorithm accuracy;
8. end-to-end test, checking for correct determination of relative position between original planning scan and final IGRT shift.

For each test, the method, frequency and tolerances used were reported, together with the provenance of the tolerance. An overview of the frequency of tests can be seen in figure 3, and the tolerances in figure 4.

Given the mix of systems studied, variation in the frequency of tests was expected – in practice this variation was significant even, for most tests, between departments with the same system. For example, the frequency with which Varian OBI systems are tested for image scaling varies between daily and 6-monthly.

In the case of geometric scaling, two questions were asked, concerning 2D and 3D geometries. One system (Tomotherapy) has no 2D mode, while others (e.g. CyberKnife) have no 3D mode. Several centres test 2D scaling but not 3D scaling or vice versa. However, in total 77 per cent of systems (92 per cent of CBCT systems) perform some form of regular image scaling QA. Tests on the ability of the system and table to implement IGRT moves are the most commonly performed, with over 90 per cent of centres performing checks at least monthly. Conversely, the accuracy of automatic registration software is regularly appraised by few centres – it is possible that the remaining departments decline to quality assure automatic registration that may be subject to manual confirmation or alteration.

Considerable variation was also seen in the tolerances applied to tests. Again, it is to be expected that variation occurs between systems, but the degree of intra-system variation was striking. For example, the tolerance on the source and detector position of Elekta Synergy systems varies between 0.5 mm and 2.5 mm. The source of tolerance, where specified, was predominantly vendor recommendation or what was achievable at commissioning. In some cases, reference to published guidance is made – such as Langen et al. for Tomotherapy QA.

Two important geometric tests are the coincidence between the imaging and treatment isocentre, and the accuracy of table registration corrections. Users typically performed both tests by imaging radio-opaque markers embedded into a phantom. Those with kV-CBCT systems compared the kV imaging isocentre to the MV radiation/imaging isocentre (64 per cent), or the in-room lasers as a surrogate, usually for the mechanical isocentre (36 per cent), but these proportions differed markedly between Varian (33 per cent/66 per cent) and Elekta (92 per cent/8 per cent) users. MV treatment isocentre can be determined from portal images at varying gantry angles. GafChromic film was also used by some Tomotherapy and CyberKnife centres. Table registration correction methods were performed by applying a known offset to a phantom and using the IGRT system to shift back to isocentre. Only 13 per cent of users were found to include rotational shifts, which suggests that rotational corrections are not routinely applied in these centres.

IMAGE QUALITY

2D tests

The only tests of 2D image quality carried out by the majority of responding centres are semi-quantitative tests of limiting contrast and limiting spatial resolution, mostly by counting circles or line pairs using the Leeds test phantom. There is a spread in frequency of these tests (figure 5), the most common being monthly, 3-monthly and annual. The other tests carried out in a few centres range in frequency and tend to be quantitative, with the PipsPro phantoms and associated software the most commonly used tools.
3D tests
The most common tests of 3D image quality, carried out by all or nearly all responding centres, are uniformity and spatial resolution (figure 6). The majority of centres carry out these tests monthly and most use the CatPhan CT test object, reflecting the fact that this phantom is commonly supplied by manufacturers with their CBCT systems (note that Tomotherapy centres use instead the manufacturer-supplied ‘cheese’ phantom). Spatial resolution is typically assessed by counting line pairs and uniformity via a range of ROI analysis techniques.

Imaging protocols and tolerances vary between centres, with some using clinical protocols and others using high-quality settings. Many centres repeat the tests for different image acquisition settings (e.g., full and half fan, small/medium/large field of view (FOV), fine/normal/coarse slice width), and some cycle through the different settings at each QC session. IQWorks appears the most common software tool for quantitative analysis. Other tests carried out by a third of centres or more are limiting contrast, HU linearity, noise/CNR, slice thickness and image rotation. None of the centres tested noise power spectrum and less than 10 per cent tested image display systems.

The most common source of tolerance quoted is the equipment manufacturer, followed by baseline or commissioning measurements, and local practice or experience. IPEM Report 32 is referenced as a source of tolerances for 2D tests. IPEM Report 91 and TG-1485 are referenced as sources of tolerances for 3D tests. Half of the responding centres use vendor-supplied software for image analysis; however, there is a range of other software in common usage such as IQWorks (popular with OBI sites), ImageJ (popular with Tomotherapy sites), PipsPro and in-house packages.

DOSE
Two aspects of dose measurement were explored: (1) tests performed during commissioning and (2) tests carried out on a regular basis as part of routine QA practices. Figure 7 shows the centres who undertake each of the various different types of measurements.

Commissioning
During commissioning, the majority of centres carry out some form of beam quality measurement and
measurements in 2D planar mode (where applicable), with both of these sets of tests being performed predominantly by diagnostic physicists (86 per cent). In volumetric imaging mode, the most common phantom for performing dose measurements is the CTDI phantom, used by all 10 Elekta users, eight out of 12 Varian users and one out of two Tomotherapy users. A known drawback of these phantoms is their relatively short length (15 cm) compared to the imaged field. However, to deal with this issue, a third of respondents reported using additional scatter material to extend the phantom’s length (objects used include a further CTDI phantom, a Tomotherapy cheese phantom and Perspex slabs).

In addition to dose measurements in CTDI phantoms, ‘in air’ measurements were equally common, being performed by 70 per cent of centres; however, other ‘in phantom’ measurements were less popular (12 per cent). These volumetric dose measurements were more evenly split between staff groups, with 45 per cent performed by diagnostic physicists, 22 per cent by radiotherapy physicists and 33 per cent by both (with only one radiotherapy centre possessing their own CTDI phantom).

Methodology in all tests varied greatly with a whole range of protocols being used. Some centres focussed on investigating a small subset of different settings while others investigated all available clinical presets. Pencil-type chambers were used by most centres, with only four respondents reporting using a Farmer chamber and one centre that used an A1SL chamber. A further variation was highlighted in terms of how doses are reported, with 42 per cent specifying dose to air, 29 per cent specifying dose to water and the remaining 29 per cent reporting dose to Perspex. Despite 12 centres stating that their dose measurements are traceable to a national standard, there was a general lack of detail specifying the calibration route and what calibration factors are applied, with many stating that a ‘composite’ factor is used and no further information being provided.

Quality assurance
In terms of routine QA, the majority of departments carry out these measurements on an annual basis;

with one centre measuring ‘in air’ and ‘beam quality’ 6-monthly and only one other centre performing any kind of monthly dose QA. Generally, the same methodology is followed as during commissioning but consisting of only a subset of measurements. An extremely wide range of tolerances were reported, ranging from +/−5 per cent to +/−20 per cent from baseline. The source of adopted tolerances was mainly locally derived although several respondents referenced IPEM Report 91.

SOFTWARE FUNCTIONALITY
Data transfer
All Synergy and OBI users had established DICOM connectivity between their planning system and image-guidance system, routinely transferring images, structures and the treatment plan. Thirty per cent of centres also transfer the dose distribution. Tomotherapy and Cyberknife have integrated planning and verification systems, but have the option of DICOM connectivity to interact with external systems.

All users perform some sort of image orientation check using phantoms like CIRS, Penta-guide (QUASAR), VHMP, Tomocheese, anthropomorphic (Randophantom) or even the patient images themselves. Usually this check is performed during commissioning only, although they will or should check for orientation during each patient registration. Image scaling is also checked routinely by 63 per cent of centres, but only 37 per cent check the sequence of the slice registration. Consistency of Hounsfield units (HU) between the treatment planning system (TPS) and IGRT system is checked by 30 per cent of centres.

Imaging parameters
All Synergy users had a version of the system containing interlocks for the type of filter, collimators and detector FOV, to avoid potential errors due to deviations from the defined presets. OBI users reported that there is not currently a hardware interlock for bowtie filter insertion.

For CBCT systems the projected images were reconstructed to different sizes depending on the size of the scan and slice thickness. Other parameters are shown in table 1. Presets for different modes were generally defined during commissioning and not routinely checked thereafter, although in some cases radiographers check the parameters prior to each scan.

CONCLUSION
The overall feedback from the survey is that there exists considerable variation in practice in both the frequency of the tests and the tolerances applied across the UK. It would be surprising if this diversity of practice was justified and probably reflects a lack of guidance. The AAPMTG-179 has recently reported providing guidance on quality assurance for CT-based IGRT systems. The working party is currently digesting this guidance to determine whether this is sufficient and appropriate for application in the UK. The current opinion of the IPEM IGRT working party is that it will write a commentary, due later in 2012, on the AAPM TG-179 report, complementing it with any specific or additional recommendations required for UK practice.

ACKNOWLEDGEMENT
Alice Futers at the IPEM office for entering the survey questions into SurveyMonkey, and all centres who submitted responses for their invaluable contributions.

<table>
<thead>
<tr>
<th>TABLE 1. Summary of reconstruction parameter responses.</th>
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<td><strong>Site</strong></td>
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<td>Head and neck</td>
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<td></td>
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<tr>
<td>Thorax and pelvis</td>
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*With the exception of two centres using 10 mm-width slices.
1 Jonathan Sykes (Leeds, Chair), Vincent Allen (Newcastle), Susan Buckley (Swansea), Karen Chalmers (Bristol), James Earley (Guildford), David Eaton (Royal Free, London), Daniel Emmens (Ipswich), Robert Farley (Stoke), Vasu Ganesan (Taunton), Syed Hassan (Preston), Helen Howard (Birmingham), Rebecca Lindsay (Leeds), Thomas Marchant (Manchester), Paul McGrane (Edinburgh), Andrew Reilly (Clatterbridge, Secretary), Andrew Robinson (Harley St, London), Michael Trainer (Manchester), Samuel Tudor (Cambridge). † The Elekta CBCT system was based on a prototype developed at the William Beaumont Hospital, Detroit, by David Jaffray and John Wong in 1997. ‡ Public domain software developed by Andrew Reilly and Ed McDonagh (http://wiki.iqworks.org).

REFERENCES


‡ Public domain software developed by Andrew Reilly and Ed McDonagh (http://wiki.iqworks.org).
Earlier this year, I was fortunate enough to receive funding via the IPEM/AAPM Travel Award to visit North America for 3 weeks, in order to learn about the widespread implementation and development of volumetric-modulated arc radiotherapy (VMAT).

The introduction of intensity-modulated radiotherapy (IMRT) 10–15 years ago highlighted a gap between the UK and North America in terms of the ability to adopt new technology. In the early 2000s, accessibility to this technique increased rapidly in the USA, and there is now a net spend of about £600 million on IMRT alone. For the NHS the uptake has been much slower. It has been estimated that, in order to achieve a target of 30 per cent of radical radiotherapy patients receiving IMRT in the UK, the cost would be around £6.6 million. Despite this relatively modest investment in NHS cancer services in the past few years has almost certainly narrowed the gap, but there still remains a perceptible difference in the availability of certain treatment options across the Atlantic.

To complicate matters, IMRT has now also been accompanied (and in some cases supplanted) by the availability of VMAT. VMAT delivery involves rotating the linac around the patient, delivering complex dose distributions dynamically by combining variable gantry speed, dose rate and multi-leaf collimator motion. Crucially, VMAT is much faster to deliver than static beam IMRT, which has obvious positive implications for workflow in busy radiotherapy departments. A number of centres in the UK are now looking to VMAT to improve the provision of IMRT, and to approach the 30 per cent target for radical patients. Many centres in the USA and Canada have replaced their entire IMRT solutions with VMAT, and I wanted to use my travel funding to see how this research filters down to the clinic. After emailing a number of centres, all of which were extremely helpful and welcoming, I organised a small ‘tour’ of the northeast, visiting New York, Baltimore, Toronto and Detroit.

UNIVERSITY OF MARYLAND MEDICAL CENTER – BALTIMORE

My first stop was the University of Maryland Medical Center (UMMC) in Baltimore, Maryland. The hospital sits in the Inner Harbour district of the city – a modern, redeveloped waterfront area which is also home to Baltimore’s major museums and sports venues. My host at the UMMC was Dr Cedric Yu, who was among the first physicists to propose delivering intensity-modulated arc therapy (IMAT) on conventional linear accelerators in the 1990s. Dr Yu and his colleagues contributed significantly to the understanding of arc therapy planning, and it is only in the last few years that linac control systems have caught up with the IMAT theory and become able to deliver plans reliably. The UMMC now delivers all prostate treatments with VMAT, along with most stereotactic lung treatments.

Whilst the UMMC is relatively small, it fosters a strong culture of research and development, and I met a number of researchers during my visit. Many of the projects were focussed on IGRT – image-guided radiotherapy. Dr Yu believes that it is the imaging technologies in radiotherapy that offer the most interest for research. While advancements in radiotherapy delivery have led to highly accurate and complex dose distributions, IGRT is still a developing field.

The UMMC is developing and improving 4D tracking of lung tumours during treatment, and is assessing a method of compensating/accounting for tumour motion by modulating the dose rate rather than the MLC leaves. Dose rate is a much simpler and faster variable to adjust than MLC aperture during treatment.
I was also interested in Dr Greg Betzel’s work investigating the tolerance of VMAT and IMRT plans to simulated MLC errors. He found that VMAT plans were more resilient to random and systematic MLC errors compared to IMRT, primarily due to the increased number of control points and rotational geometry, which offers somewhat more compensation for individual leaf errors.

**MEMORIAL SLOAN KETTERING CANCER CENTER – NEW YORK**

From Baltimore to New York it is a 3-hour bus journey north, following the East Coast highway. The Memorial Sloan Kettering Cancer Center (MSKCC) is situated in Upper Manhattan, nestled among the iconic skyscrapers of the city. It was interesting to consider the practicalities of building a 10 linac radiotherapy department within a 23-storey building in such a densely built area. Indeed, it turns out that the linacs themselves aren’t as much of a problem as their Gamma Knife unit is – source changes require a huge crane, 20 tonnes of shielding and a removable ceiling.

The MSKCC is a world-renowned centre for research and development in radiotherapy. Dr Perry Zhang, who works mainly in treatment planning, helped to organise my visit and arranged for me to meet some of their post-doctoral researchers. Sloan Kettering has a strong focus on radiotherapy software development, and they use their own in-house systems for IMRT and VMAT planning. Dr Zhang was heavily involved in this, and demonstrated some of his work on optimising collimator trajectories for their VMAT paraspinal treatments. This system looks at the orientation of the spinal cord over the arc and finds the optimum collimator rotation for each gantry angle, so as to best conform to the shape of the tumour and avoid the cord during treatment.

I also observed some research on fiducial marker tracking in prostate VMAT treatments. By analysing concurrent MV and kV images taken during treatment, it is possible to determine the 3D position of the markers embedded within the prostate, and thus track the position of the prostate during treatment. Such a system could lead to a reduction in treatment margins and possible dose escalation or improved normal tissue avoidance.
PRINCESS MARGARET HOSPITAL – TORONTO
In February the temperature in Toronto can drop to −20ºC, which is why, I’m told, the Princess Margaret Hospital doesn’t often get visitors in the winter months. Nevertheless, donning my warmest hat and coat, I braved the weather and spent a week at the PMH, where my visit was organised by Dr Michael Sharpe and Dr Mohammed Islam. The PMH has a very large and impressive radiotherapy department in Toronto, and provides physics support to two smaller cancer centres in the outskirts of the city. During my time there I had the opportunity to speak to a number of physicists about their experience of VMAT and other delivery techniques.

As is the case with many larger radiotherapy centres, PMH are aiming to utilise VMAT in order to improve patient throughput. Prostate IMRT has already been replaced by single arc treatments, and more simple head and neck cases are also being treated with VMAT. Perhaps the most significant time advantage, though, has come through the use of VMAT for stereotactic lung and liver treatments. Previously, fraction times were up to an hour using IMRT, but have been almost halved through the use of single or dual arc treatments.

I was particularly interested in how PMH deal with VMAT quality control, both for the patient plans and for the linac itself. The department has a comprehensive QC regime which includes the use of pre-treatment verification alongside routine machine tests. Dr Stephen Breen and Dr Daniel Letourneau introduced me to their QC system, which includes a web-based database for recording the results of all tests – in some cases directly from the measurement device. Using such a system has enabled the department to analyse long-term trends in QC results, and if necessary inform of any potential changes required to the linac parameters or even to the treatment plans used.

The use of software to speed up and improve departmental workflow is also evident in the treatment planning section. I spoke to Dr Tom Purdie, who has developed a method for automating simple treatment planning and checking. His system currently works for breast IMRT treatments, but has the potential to be rolled out to other sites. Using a set of scripts, alongside external software, acceptable treatment plans can be generated on new patient CT sets with minimal planner involvement. Treatment planners then assess the dose distribution visually and – in most cases – the plans do not require any further changes. Such a system, Dr Purdie explained, allows planners to concentrate on more complex treatments rather than a large number of time-consuming, simpler plans.

The PMH Physics Department is headed by Dr David Jaffray, a physicist who was one of the original developers of cone beam CT for radiotherapy. As such, the department has a very strong interest in IGRT, and I was introduced to a number of ongoing projects in this field during my visit. Foremost amongst these projects was the development of a magnetic-resonance (MR) guided linac. Speaking to Dr Teo Stanescu, an imaging physicist at the PMH, the significant benefits of MR-guided radiotherapy became apparent, as it offers very high-quality images for patient localisation and monitoring. The PMH are currently working on overcoming the main difficulties involved in MR guidance, including managing the impact of the magnetic field on the linac beamline, and correcting for geometric distortions in MR images.

I also observed cutting-edge IGRT research at the SITTAR Institute (Spatio-Temporal Targeting and Amplification of Radiation Response), which is also led by Dr Jaffray. This modern laboratory is dedicated to improving radiation response through novel imaging techniques. Focussing mainly on small animal studies, the centre has micro-CT, MR, SPECT and PET facilities, a larger 7 tesla MRI and a number of precision IGRT machines. It was very interesting to meet the large multi-disciplinary team of physicists, biologists, biochemists, oncologists, computer scientists and engineers – all of whom were working towards the common goal of improving the effectiveness of targeted radiotherapy.

Before I left Toronto I headed down to the impressive Niagara Falls, which was eerily devoid of other tourists because of the freezing temperatures (−15ºC if you include wind-chill’, I was assured by a rather unsympathetic bus driver). For the final leg of my visit, I then travelled down to the relatively tropical (+1ºC) climate of Detroit, Michigan.

BEAUMONT CANCER CENTER – DETROIT
The Beaumont Cancer Center is situated a few miles outside of downtown Detroit, forming part of the Beaumont Health System which consists of three hospitals around central Michigan. During my short visit here I was hosted by Dr Neelam Tyagi, who arranged for me to meet with a number of people in the department.

As with the previous centres, the Beaumont are actively moving towards VMAT for many of their complex treatments. I was interested to learn of their work on improving VMAT dosimetry – they employ a system where the final planned dose calculation is performed at a very fine gantry angle resolution (down to 1º) in order to achieve more accurate pre-treatment QC results.

The Beaumont have a history of developing novel treatment regimes, and I was particularly interested in visiting this centre because of their work on adaptive radiotherapy. Dr Jian Liang demonstrated their adaptive solution, which includes the use of a novel piece of software to calculate the accumulated dose to the patient based on daily cone beam images. For prostate patients, a new plan is created after a number of fractions, taking into account the changes in patient anatomy, and the dose which has already been received by the target volume. Their system is highly automated – outlining can be quickly performed on the new data sets with an in-house deformable registration tool. While currently limited to prostate cases, the Beaumont have been able to reduce their treatment margins significantly, and a recent publication from the centre has demonstrated a clinical benefit for patients receiving adaptive IGRT.

In summary, I found the experience extremely rewarding. I learned a great deal about the adoption of VMAT as a treatment technique, and its potential in the clinic. Being able to speak to experts in the field of IGRT was also valuable and I certainly gained an appreciation of where radiotherapy appears to be heading. I would encourage anybody considering applying for a travel award to do so – it is a fantastic opportunity to view our profession from another angle. Finally, I’d like to thank IPEM, AAPM and all of the centres I visited for their time and hospitality.
CEREBRAL HAEMODYNAMICS: MEASUREMENT AND MANAGEMENT

TONY BIRCH University Hospital Southampton

IMPERIAL COLLEGE, LONDON 7 July 2011

THIS ONE-DAY MEETING ON CEREBRAL haemodynamics had an impressive international representation, attracting delegates from 13 different countries including the US, New Zealand, Canada, Japan, China and Uruguay, with the remainder from inside Europe. This appears to have been the strongest international participation at an IPEM one-day meeting. The response shows a healthy worldwide level of interest in this topic and also reflects a good strategic decision by the organisers to run the meeting the day after and in the same venue as the inaugural meeting of CARnet (Cerebral Autoregulation Research Network), a network of researchers with a common interest in measuring cerebral autoregulation.

CEREBRAL AUTOREGULATION MEASUREMENT

The meeting started with an invited talk by Richard Hughson (University of Waterloo, Canada), who introduced the topic of cerebral autoregulation measurement. He outlined the difference between autoregulation to blood pressure changes and reactivity to CO2 and also the pitfalls of measuring one without taking the other into consideration. He controversially advocated the use of cerebrovascular resistance in models of cerebral autoregulation, given by the index CVRi = BPMCA / CBFV, where BPMCA is blood pressure at the level of the middle cerebral artery and CBFV is cerebral blood flow velocity. He also stressed the difference between blood flow and velocity, presenting evidence that changing the diameter of the middle cerebral artery occurs under some conditions, which means that they do not always change proportionally with one another. The first proffered paper of the day was from Caroline Rickards (University of Texas at San Antonio, USA). She presented an unexpected and fascinating observation that subjects under induced hypotensive stress, who exhibit large low-frequency oscillations in blood pressure and cerebral blood velocity, tolerate hypotension for longer without symptoms of syncope than those who do not exhibit such large variations. She argued that the large variations may provide a protective effect. Next Angela Darekar (University Hospital Southampton) gave a presentation describing the use of MR to image dynamic cerebral autoregulation. She measured the BOLD (blood oxygenation level dependent) MRI signal during blood pressure manipulations using thigh cuffs and the valsalva manoeuvre, and demonstrated a signal change consistent with model predictions. However noise inherent in the signal currently limits image quality. There followed a presentation from Shieak Tzeng (University of Otago, New Zealand) who posed some challenging questions, not least of which was: if gain and phase in the frequency response are both measures of cerebral autoregulation, why are they so weakly correlated with one another? Lastly before lunch Andrew Robertson (University of Waterloo, Canada) presented results comparing intracranial and extracranial blood flow responses to standing. Reassuringly, the cerebral circulation demonstrated better autoregulatory behaviour, as predicted.

METHODS TO MEASURE CEREBRAL AUTOREGULATION

After lunch, Matthias Reinhard (University of Freiburg, Germany) gave the second invited presentation of the day. This was an excellent review of methods that have been used to measure cerebral autoregulation followed by a discussion of how the measurements can translate into clinical practice. Applications can be broadly divided into two groups: (1) those that use a snapshot measurement for grading the impact of conditions such as carotid stenosis or orthostatic intolerance in an outpatient setting and (2) autoregulation monitoring in intensive care, where the concept of autoregulation-orientated therapy (AOT) is currently being explored. There followed two presentations from the University of Cambridge describing the use of NIRS (near-infrared spectroscopy). Firstly, Peter Smielewski discussed the assessment of cerebral autoregulation, showing how NIRS might be used to find optimal arterial blood pressure in traumatic brain injury management, and secondly Pippa Al-Rawi considered the assessment of cerebral blood flow using indocyanine green: the measurement shows potential, but extracranial contamination remains a problem. We were then treated to a broad ranging presentation from Vera Novak (Beth Israel Deaconess Medical Center, Boston, USA) summarising and bringing together many aspects of the field. Emmanouil Katsogridakis (University of Leicester) then presented a neat description of autoregulation measured using pseudorandom binary sequences of thigh cuff and CO2 administrations to stimulate an autoregulatory response. Use of the stimulus produces an improved sensitivity and specificity to CO2-impaired autoregulation.

To test the staying power of the audience the meeting finished with two presentations focussing on data analysis and modelling methodology. First, Hesam Koochakpour (University of Southampton) described applying the sub-space distance method to optimise measures of autoregulation from spontaneously varying blood pressure and flow, and finally Georgios Mitsis (University of Cyprus) gave a detailed review of black-box data-driven modelling applied to cerebral autoregulation.

In summary, the meeting brought together many of the internationally leading groups in cerebral autoregulation research and related topics. The very stimulating presentations and discussions provided strong motivation to hold similar meetings in the future.
EUROPEAN MEDICAL PHYSICS AND ENGINEERING CONFERENCE 2011

TOM BURROWS  London North Medical Physics Training Consortium

TRINITY COLLEGE, DUBLIN, IRELAND  1st–3rd September 2011

THIS YEAR THE IRISH ASSOCIATION OF PHYSICISTS in Medicine (IAPM) hosted the European Federation of Organisations for Medical Physics (EFOMP) fifth annual Medical Physics Conference in Dublin, Ireland. A major focus of the conference was the concept and strength of European partnership. Medical physics in Ireland has developed greatly in the past and continues to grow. IPEM also held its annual Medical Physics and Engineering Conference (MPEC) here.

The venue, Trinity College, Dublin, is a well known and respected university and the conferences were held during the tercentenary year of its medical school, one of the oldest in Europe. The aims of the conference were to:

- represent the diverse activities in medical physics and engineering of all countries in the expanded Europe;
- unite professionals from different countries so that research programmes and themes can be developed as collaborations and in unison;
- present state-of-the-art research to a wider medical physics and engineering audience in a convivial environment in one of Europe’s most interesting and lively cities;
- provide equal access to medical physics and engineering professionals across all EU countries to attend a landmark conference in Ireland.

The conference was superbly organised with some truly excellent speakers and poster presentations. There were also several companies present in the exhibition area showcasing new developments from the industry.

The opening ceremony consisted of a welcome note from Barry McMahon, Chair Person Organising Committee (Trinity College Dublin). After this the crowd was treated to Songs of Joyce by The Shannon Colleens and welcome addresses from Stelios Christofides (President, EFOMP) and Elke Anklam (Director, European Commission Join Research Centre, Institute for Health and Consumer Protection).

A huge range of talks were on offer and one of those I attended was the EFOMP symposium for hybrid imaging systems in diagnosis and radiotherapy. Bas Raaymakers (University Medical Centre Utrecht, The Netherlands) presented his work on ‘MRI-linac: underlying physics and perspectives’. This involved the integration of closed bore 1.5Tesla MRI system with a 6MV linac allowing simultaneous irradiation and MRI imaging.

Another stand-out presentation was from Aonghus Murphy (Whitfield Clinic Waterford, Ireland). Mr Murphy’s talk on ‘The accuracy of whole scalp RT using static IMRT technique’ shows the high calibre of medical physics work being completed in Ireland at the moment.

► FIGURE 1. Head phantom and bolus (A. Murphy).

Completed Bolus & Immobilization
Automated Checking Tool

- The chart review software is implemented to have minimal impact on current work practices.
- The check is done after planning but before physics check.
- Runs in background unless a potential error is detected.
- The software will email physicists responsible for treatment plan review with information on the error.

**FIGURE 2.** Complex slide calculation vs. measured dose results obtained using wedge profile measured with LA48 (A. Murphy).

**FIGURE 3.** Schematic of automated chart review (P. Collins).

**Complex Case: Linear Array**

Complex Case using LA48 Calibration Curve

\[ y = 0.9449x \]
\[ R^2 = 0.9705 \]
The homogeneous irradiation of the whole scalp has technical and dosimetric challenges associated with it due to the extensive, superficial and concave treatment volume of the region. IMRT offers a means of treating not only the simple lesions, but also the more complex targets. This study aimed to improve the IMRT treatment technique for whole scalp lesions and also verifying this improvement.

This study investigated the characteristics of EBT2 GAFchromic film for routine clinical in vivo dosimetry verification of IMRT scalp treatment plans. The calibration of EBT2 film using a 60-degree wedge profile method was found to be much quicker and more accurate when compared with that of the standard method. The EBT2 film was used to verify the measured dose under reference conditions to within 2–5 per cent precision of the standard method, up to a dose of 250 cGy.

Typical scalp targets, ranging from simple to complex, were marked on a head phantom. A helmet-like bolus of at least 1 cm thickness was constructed of thermoplastic sheets which were used to cover the scalp target (as can be seen in figure 1). It was found that an equally spaced coplanar 12 beam IMRT plan gave optimal dose distribution for all cases. The recorded in vivo dose measurement represented actual skin dose data under the helmet bolus, for the respective IMRT plans. The majority of the in vivo data recorded using the EBT2 film underestimated the delivered dose by approximately 10 per cent, while the LA48 calibration curve showed slightly better results compared to the standard method (see figure 2).

Indeed it was found that those points differing from the calculated dose by greater than 10 per cent were mostly located under large air gaps between the bolus and the phantom surface. Accordingly, further study is needed to investigate methods to reduce the inherent air gap by possibly using water/gel pouches.

Another impressive talk came from Paul Collins (Cork University Hospital, Ireland) which dealt with the development of automated chart review software (figure 3). Safety is defined by the World Health Organization as the reduction of risk of unnecessary harm to an acceptable minimum. This minimum is achieved through the best use of knowledge and resources available. The study used resources available in most radiotherapy departments to create an early warning system that assists in halting potential errors from progressing.

Software was developed upon open-source projects using the Python programming language to access treatment plan data via the DICOM -RT standard. The treatment plan review software created is automated, has no additional time cost and provides an additional defence barrier for patient safety. Any potential errors detected are emailed to the physicists responsible for treatment plan review. The checks currently implemented in the department include verifying the

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treatment plan is compatible with the in-house Siemens Linacs’ monitor unit delivery constraints for virtual wedge fields. This project showed considerable scope to develop the automated review process to include a broad range of checks to further reduce the possibility of an adverse event progressing as far as patient delivery.

Other exciting guest speakers included Willi Kalender (Friedrich-Alexander-University Erlangen-Nürnberg, Germany) who delivered the IPEM Woolmer lecture on his role in the development of spiral CT. The O’Connor lecture was delivered by Thomas Mackie (University of Wisconsin, Madison, USA) where he discussed his vast experience in radiotherapy. Dr Mackie gave a very interesting talk which brought together all the areas of radiotherapy in a new and interesting way.

Overall EMPEC 2011 was a huge success and I found it a very interesting conference to attend (figures 4 and 5). It brought together physicists from all over the world – both new trainees as well as some of the most experienced people working in the fields of medical physics and clinical engineering today. I believe it showed the potential for collaboration across Europe as well as highlighting the excellent work being completed by physicists working in the host country of Ireland. I, along with my fellow trainees, am looking forward to the Medical Physics and Engineering Conference 2012 (MPEC 2012) which will be held in Oxford between 10th and 12th September 2012.
Love and marriage, love and marriage,
Go together like a horse and carriage.
This I tell you, brother, you can't have one without the other...

FRANK SINATRA HIT THE NAIL ON THE HEAD

when he aired this memorable tune with its theme of harmonious union. Conversely, and with an air of desperation, it was proving difficult as London Chair of IPEM to identify an organisation and venue that was eager to host a scientific meeting complementing the professional interests of IPEM London members. Guilt had been raising its ugly head through not having organised a scientific meeting in 2010 and the previous one, ‘Physics and imaging in medicine … no bitter pill to swallow!’ at the Royal Society of Medicine in 2009, made me unwell … surely an ill omen. In salvation the National Physical Laboratory (NPL) sprang to mind. It had always appealed as a place to visit owing to its huge profile and worldwide reputation for scientific excellence but for the very same reasons there was equal apprehension about going myself; even though figuratively speaking it was located on my very own doorstep!

This thought struck a chord with concerns over reduced ease of access to some of the large scientific institutions based in and around the London region for non-London IPEM members. Accordingly it made sense to invite ALL IPEM members, giving those in further out regions an equal opportunity to participate. NPL has developed and maintained the UK’s primary measurement standards for more than a century. Such standards are the basis of accurate, consistent measurements and traceability worldwide. NPL have an international reputation in a wide range of fields (see http://www.npl.co.uk). IPEM and NPL have collaborated in the past but this one-day venture seemed a good idea to fashion a new intimate relationship between our organisations for the future.

It made sense to send a questionnaire to all our members asking what topics they would like to see at NPL and in order of preference so we could try to match their expertise with our expectations. Figure 1 shows a plot of the responses collated from all members showing preference of disciplines at NPL.

It was a wonderful to see NPL deal with all the complexities of setting an agenda for the open day in an efficient and friendly manner that closely accommodated our questionnaire responses. The agenda we negotiated and finally settled on consisted of morning lectures by NPL staff with a poster session at lunch followed by a tour of NPL’s exciting laboratories in the afternoon. NPL very kindly waived any fees for the open day which included lunch and this was much appreciated by IPEM as it surely encouraged some members to attend who may have had difficulties with funding otherwise.

ON THE BIG DAY

Entrance to the venue was achieved by showing security a printed-out access pass, received by email after registration – very efficient. The main building façade was most impressive with a grand frontal elevation in accordance with my anxiety levels, as it was impossible to estimate how many of us would actually attend on the day! Once inside the reception it was a great relief to see that we were at our limit of 100 members (figure 2). After picking up name badges and tea we progressed to the lecture room.

LECTURES

My opening address in the packed hall as London IPEM Chair was spectacularly pedestrian but then NPL Deputy Director Martyn Sene offered us a fascinating overview of NPL structure, work and influence globally. After, Julia Snaith exposed us to an absorbing talk on radiation dosimetry for radiotherapy and fears of the open day’s success disintegrating started to decay exponentially as Andrew Fenwick (figure 3) gave a scintillating talk on radionuclide metrology for medical applications.

On a different note, this was followed by a reflective presentation resonating the importance of acoustics in healthcare focussing on ultrasound by Bajram Zeqiri. After the tea break our next target was a charged presentation on neutrons in medicine scattered with historical perspective by Graeme Taylor. Maurice Cox with high probability left me uncertain of my statistical ability after his precise presentation on measurement uncertainty evaluation. Lunch beckoned and we had the opportunity to interact with friendly NPL staff, other members and to view the posters on display (figures 4 and 5). With my IPEM hat in place I should mention that these interactions are like gold dust for networking and offer the potential of making new acquaintances that can lead to future contacts, collaborations and friends too.

Following lunch Alex Shard’s organic presentation style on biosensing made us feel more alive and Simon Hall lit up the room with his illuminating presentation on optical metrology. In short the morning talks were all very informative, well presented, much appreciated and acted as a great introduction to NPL’s work. A podcast of the lectures was kindly made available at http://www.youtube.com/playlist?list=PL99EE211EF65CDA41&feature=mh_lolz. The talks also served to whet the appetite for laboratory tours that were greatly anticipated by our questionnaire responses.

LABORATORY TOURS

We were split into groups of 10 or so for the laboratory tours. Clearly this was a demanding task logistically for NPL to manage; especially with our members having such a diversity of interests. As an eventual compromise we had more sections to visit but less time to spend in...
Response from 100 members across the UK revealing ionising radiation (82 votes) as the most popular discipline.

Members of Mount Vernon Hospital in Northwood enjoying refreshments.

Andrew Fenwick’s presentation to members across the UK.

A spot of lunch before heading back to lectures and laboratory tours.

Members congregating by the posters.
each which seemed a very fair price to pay in my humble opinion.

Members visited a number of laboratories including solid state lighting (figure 6), ion chamber, primary standards, blood pressure, biosensing and ultrasound (figure 7) (my favourite!) as examples. The tours were fascinating and they all proved a great success.

**ANALYSIS OF THE OPEN DAY**

Thankfully everyone appeared to genuinely enjoy the day with only minor niggles aired. To quantify these thoughts for more objective analysis later, members were asked to feed back their views via yet another questionnaire. This time we individually graded (1: excellent, 5: very poor) the lectures, tours, overall impression and whether we would recommend other members visiting. IPEM membership status and suggested changes to improve each personal experience for future visits were also asked.

The responses are shown in figure 8. The first reassuring fact was that there were no 4s or 5s and it would have been a genuine surprise and a great discourtesy to our hosts to have seen these following the high standards we experienced.

It is apparent that lectures, tours and overall experience were much appreciated and received high grades. In evidence nearly 80 per cent of attendees who responded would recommend a similar meeting to colleagues as being excellent. The majority of attendees who responded were trainees principally with interest in radiotherapy and nuclear medicine disciplines, as depicted in figure 1. Suggested improvements concentrated on spending more time in laboratories relevant to each individual’s own discipline resulting in less fatigue during the day. This is understandable and clearly was the compromise between 100 of us simultaneously attending with diverse interests and the enormous logistical operation of managing such a challenging event. I was more than pleased with the end results as a first run for this event. Hopefully many will seize the opportunity to visit more often and engage in collaborative work in the future.

**SUMMARY OF THE OPEN DAY**

From my perspective the day went very well and we came back with the potential of having made new professional contacts and friends while gaining more knowledge in our own and other relevant disciplines. NPL were an excellent host and I would like to thank their organisation and personnel for their courtesy in hosting and managing this first IPEM–NPL open day with such aplomb and making us all feel welcome, particularly Andrew Fenwick and Hannah Carter. Only time will tell if this meeting is repeated, becomes a regular event or is modified to accommodate specific groups and focussed interests. I suppose just like marriage it’s what we want to make of it.

So, what do you fancy, a short hot affair or a long, loving marriage? …You choose!
ON 21ST OCTOBER, A YEAR AFTER THE publication of IPEM Report 32 VII, an impressive number of delegates gathered at the British Institute of Radiology (BIR) in London to discuss their ‘Experiences with the testing of CR and DR systems’.

Alistair Mackenzie (National Coordinating Centre for the Physics of Mammography, Guildford) provided a summary of the origins of the report and discussed the possibilities of using quantitative techniques such as the modulation transfer function (MTF) and noise power spectra (NPS) to assess digital image quality. He also highlighted issues with commissioning an energy compensation calibration for automatic exposure control (AEC) systems.

COMMISSIONING AND ROUTINE TESTING
The first group of presentations focussed on the commissioning and routine testing of CR readers and DR systems. Issues with a variety of CR manufacturer’s DDI (detector dose index) calibrations at commissioning and their reproducibility over time were discussed by both Matthew Prior (Royal Surrey County Hospital, Guildford) and Mark Worrall (NHS Tayside, Dundee). It was suggested by Matt Pryor that testing the manufacturer calibration should be included in the annual QA protocol. Mark Worrall focussed on the practical issues with achieving an accurate manufacturer’s DDI calibration in both CR and DR systems. He went on to question the clinical usefulness of the DDI values, although there was not wide agreement with this from the audience. The signal transfer properties (STP) of a variety of different system manufacturers were also discussed, and this demonstrated that there was poor consistency between units from the same manufacturer. A number of units had a linear correlation with an R² fit <0.98. As a result of the poor correlation, linearisation errors are inevitable and could have a significant impact on quantitative tests including SNR and uniformity.

A more streamlined QC programme was on the agenda in several of these presentations. Navneet Dulai (Kings College Hospital, London), for example, suggested the removal of certain tests including erasure cycle efficiency, scaling errors and blurring whereas Worrall went a step further and concluded that biennial testing of CR readers was sufficient.

The accepted number of adjacent ‘dead lines’ on flat panel detectors was discussed by Ian Honey (Guy’s Hospital, London). IPEM Report 32 VII suggests that two or more defective adjacent lines should not be accepted at commissioning. The importance of including a statement regarding the number of adjacent dead lines a manufacturer deems acceptable in any tender documents was illustrated, as six out of 430 detectors commissioned showed two or more defective adjacent lines.

The calibration, commissioning and routine testing of AEC systems can be completed using a range of methodologies. The meeting went on to demonstrate the advantages and disadvantages of the various methodologies used at a selection of centres.

ADVANTAGES AND DISADVANTAGES OF THE VARIOUS METHODOLOGIES
Variances in the AEC response curves and dose cut-off levels for a range of units being used with CR imaging systems were discussed by Jonathon Shafford (Royal Surrey County Hospital, Guildford). Target receptor doses were set based upon both those recommended by the manufacturer and minimum receptor doses inferred from manufacturer’s recommended DDI ranges. Four rooms at a local district general were then optimised using the in-scatter methodology which resulted in a consistent departmental receptor dose across the range of tube potentials. The creation of some clever jigs by Matthew Ager (Singleton Hospital, Swansea) enabled detector air kerma (DAK) measurements to be made in both the ‘scatter’ and ‘scatter free’ methods outlined in IPEM Report 32 VII. Additionally the differences arising from completing the AEC calibrations on DR systems for the different methodologies were rigorously investigated. The conclusion of this work was to ‘choose a method and stick with it’ for the calibration, commissioning and routine testing which is essential to ensure that all measurements can be correctly compared to baseline.

Time management was also discussed by Matt Ager, who suggested that for routine testing, the cut-off pixel value could be compared to baselines to prevent having to directly measure the detector air kerma. Chris Baker (Mount Vernon Hospital, Northwood) utilised a cut-out in an old AGFA CR cassette so that the DAK could be directly related to DDI under certain test conditions. In routine testing, the DAK could then be used to infer the DDI and hence eradicate the time-consuming cassette processing. Ionnis Delakis (Imperial College Healthcare NHS Trust, London) suggested reducing the required testing time by establishing a relationship between the mAs and both the DAK and DDI for the range of potentials and copper attenuator thicknesses when using the Report 32 scatter method.

OUTLOOK FOLLOWING IPEM REPORT 32 VII
The general outlook from the meeting is that the publication of IPEM Report 32 VII has been beneficial in helping progress to a standardised methodology for testing CR and DR systems. It was clear, however, that significant variations in chosen methodologies exist, and that for most centres, a move towards more quantitative techniques remains some way away.
PASS OR FAIL: DETERMINING ACCEPTABLE MEDICAL DEVICE GOVERNANCE

ALYTE PODVOISKIS  Asteral Ltd, Hillingdon Hospital, Uxbridge

IPEM OFFICES, FAIRMOUNT HOUSE, YORK, 1st November 2011

ON 1ST NOVEMBER 2011 THE Clinical Engineering Special Interest Group (CESIG) held a meeting at Fairmount House entitled ‘Pass or Fail: Determining Acceptable Medical Device Governance’. The aim was to bring together clinical engineers to share ideas and practice for demonstrating compliance with the ever-increasing demands of medical device guidance, standards and legislation and to evaluate the acceptability of this with the help of a number of invited experts. The format of the meeting was a break with tradition and involved three workshop sessions to allow plenty of discussion. The session topics were determined by suggestions put forward by IPEM members.

The day started with introductions from the invited experts Duncan Astill (Mills and Reeves, Cambridge) and Tony Sant (MHRA, London), whom the CESIG were very pleased to welcome to the meeting.

Duncan Astill, a Healthcare Lead for the Eastern region and London, brought to the meeting experience of medical device-related manslaughter and health and safety inquests. He described the actual legal obligations on clinical engineering departments (figure 1) and suggested that going forwards it would be difficult to use an economic argument as a means of justifying actions. He stressed the importance of recording reasons for adopting procedures, particularly where they differ from manufacturer’s recommendations.

Mr Tony Sant, Group Manager of the Devices Division for the MHRA, attended with the joint purpose of sharing expertise and identifying ways in which the MHRA could improve their service. He provided an overview of the MHRA and the 2011 adverse incidents, noting that the number one cause of incidents was still user error.

After the initial introductions the three workshop sessions commenced, themed around a phrase coined by Nick Abraham (Imperial College Healthcare NHS Trust, London): ‘Buy It Right, Use it Right and Keep it Right’.

SESSION 1: BUY IT RIGHT

During the first session Chris Hacking (United Lincolnshire Hospitals) presented the workshop groups with the scenario of replacing a patient monitoring system and asked each to discuss different stages of the procurement critical path.

The initial stage considered the identification of need. General consensus was that triggers for identifying need and the members of procurement panels were the same. Prioritisation was discussed and comments made about business cases that do not include reference to the income generated by having the equipment.

Legal requirements

- **Criminal Law**
  - Corporate Manslaughter and Corporate Homicide Act
  - Health and Safety at Work Act 1974
  - Provision and use of work equipment Regulations 1998
  - Health & Social Care Act 2008 (Regulated Activities) Regs 2010

- **Civil Law**
  - Negligence & breach of statutory duty

- **Best practice**
  - MHRA: Managing medical devices
  - NHSLA: CNST standards

MILLS & Reeve
The next stage discussed was procurement itself, including the tender process. Many agreed that the tender would include technical, clinical and financial specification with an increasing focus on patient outcomes but warnings were given against being too specific. It was suggested that departments would benefit from sharing specifications and distinguishing between ‘essential’ and ‘desirable’ requirements.

Consideration was then given to the final stage of procurement, actually putting the devices into service including acceptance tests which led to discussions about naming conventions and the Global Medical Device Nomenclature (GMDN).

SESSION 2: USE IT RIGHT
Session 2, ‘Use it Right’, was chaired by Paul A. Blackett (Lancashire Teaching Hospitals NHS Foundation Trust, Preston). The aim of this session was to look at the elements of the standards and guidelines that focus on the actual patient interface. The key topics that were discussed were:

■ **Availability** – generally this was thought to be beyond the remit of clinical engineering departments, however it was noted that there was a difference between availability and shortage and that there was a need to define both before identifying measures. Delegates commented on the lack of guidance for quantities of medical devices as there was for radiotherapy and it was noted that there may be a potential need to revisit RFID feasibility.

■ **Patient needs** – discussions were had about how to define and measure the needs of patients and the contributions of clinical engineering departments, especially at the design and procurement stages, and when working at the patient interface.

■ **User training** – there was a mixed approach to the level of involvement and responsibility of engineering departments to user training which was deemed acceptable. All agreed that clinical engineering would have a part to play in communicating data relating to repairs resulting in no fault being found and those resulting from user error.

■ **Auditing** – there was also a mixed approach to the level of involvement and responsibility of clinical engineering departments’ auditing equipment management. It was agreed that compliance with ISO 90001 would certainly help demonstrate compliance and was also compatible with fulfilling the patient (customer) requirements.

SESSION 3: KEEP IT RIGHT
Session 3, ‘Keep it Right’, was chaired by John Amoore (NHS Ayrshire and Arran, Kilmarnock). The discussions in this session revolved around revisiting some commonly arising questions relating to the conflict between guidance and practice, such as with what frequency planned maintenance should be carried out, whether it is being done in accordance with manufacturers’ instructions, whether manufacturers are following their own instructions, who should be carrying out maintenance, and whether risk-based protocols are acceptable.

Some further interesting contributions were made by Duncan Astill, who gave insight into peer review being used to judge acceptability of decision making, and also by Justin McCarthy (Chair of the IEC 62353 standards panel) who notified those present that a proposal had been put forward for inclusion of a statement in the standard relating to the revision of manufacturers’ instructions based upon experience and risk assessments carried out.

A FINAL NOTE
The workshop covered a magnitude of topics and whilst much knowledge and guidance was shared, many more questions were also raised. CESIG hopes to organise more meetings over the coming year to tackle in more depth specific issues arising from the meeting. Thanks to all those who participated in the meeting and provided feedback on the novel format of the day.

MR SAFETY UPDATE: PRACTICAL UPDATE ON CURRENT ISSUES IN SAFETY
AARON MCCANN Regional Medical Physics Service, Belfast Health and Social Care Trust

EXPANSION IN THE USAGE, COMPLEXITY AND power of MR in medicine continues apace. These changes bring with them new concerns for those tasked with ensuring the safety of patients, staff and others entering the MR environment. Contributors to the biennial MR Safety Update sought to clarify and address these concerns, and as such it was a meeting of great importance and immediate use to the 120 physicists, radiographers and other professionals attending.

IMPLANT SAFETY
A full house at the Society of Chemical Industry in London welcomed keynote speaker Frank Shellock (University of Southern California; Institute for Magnetic Resonance Safety, Education and Research, www.IMRSER.org, Los Angeles, CA, USA), the world authority on MR implant safety. His presentation was a comprehensive and up-to-date overview of the many implants, devices, foreign bodies and other pieces of equipment that may require entry into the MR department for a scan to be facilitated.

The various elements that comprise the MR scanner can have serious adverse effects on such objects: projectile and torque forces due to the static magnetic field; heating due to the deposition of energy from radiofrequency (RF) pulses or currents induced by field

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The various elements that comprise the MR scanner can have serious adverse effects on such objects: projectile and torque forces due to the static magnetic field; heating due to the deposition of energy from radiofrequency (RF) pulses or currents induced by field
gradients; peripheral nerve stimulation due to rapidly switching field gradients, and compromised function of active implants (such as cardiac pacemakers or neurostimulation systems) for a number of reasons. Professor Shellock gave insight into the testing procedures he has implemented for quantifying these effects for specific implants, allowing their classification as ‘MR safe’, ‘MR conditional’ or ‘MR unsafe’. The field strength and frequency (e.g. 1.5T/64 MHz) at which such tests are performed specifies the conditions under which it may be safely scanned – it was demonstrated that making assumptions of safety even at a lower field strength and frequency than shown to be acceptable is inadvisable (figure 1).

The increasing availability of 3T scanners must be accompanied by an awareness of additional restrictions these impose on the scanning of implants and – as stressed by the speaker – reinforces the necessity of rigorous screening, labelling, policy making and education in any MR department. Professor Shellock has, for more than 25 years, freely provided the international MR community with safety advice and information specific to thousands of medical implants and other items via his website (www.mrisafety.com), and further demonstrated his generosity by supplying each delegate at the meeting with the latest edition of his best-selling reference manual.

The next talk by Anastasia Papadaki (Imperial College Healthcare NHS Trust, London) focussed on RF heating of hip implants in 3T fields. Drawbacks of existing techniques for measuring temperature increases were discussed. A numerical simulation was introduced allowing the user to model \textit{in vivo} heating effects in unilateral or bilateral implants, in male or female whole-body models. The model suggests that hot-spots well beyond the acceptable limits of temperature increase may occur if implants are near the centre of a local transmit coil.

**TECHNOLOGICAL ADVANCES**

Citing the statistic that ‘50–75 per cent of patients with implantable cardiac devices will be indicated for MRI scans over the lifetime of their device,’ Ralph Niblett (Medtronic, Inc., Watford) introduced his company’s range of ‘SureScan’ cardiac pacemaker systems. Many technical challenges were overcome to gain ‘MR conditional’ status for a device that has historically been the primary contra-indication for patients referred for an MR scan. The devices were subjected to extensive clinical and non-clinical testing prior to their approval. Dan Wilson (Leeds Teaching Hospitals NHS Trust) supplied the complementary experiences of an MR department faced with scanning a patient implanted with such a device. He stressed the importance of assembling a multi-disciplinary team (radiographers, clinical physiologists, medical physicists, radiologists and cardiologists) whose roles and responsibilities with regard to fulfilling device-specific MR conditions are well defined. Strategies for keeping within SAR (specific absorption rate) limits and issues with device identification from chest x-rays were also discussed. The accompanying poster session featured two contributions on the same theme, confirming that the emergence of these devices (and similar systems from Biotronik and St Jude Medical, Inc.) is a ‘hot-button’ topic in MR.

Antonis Kalemis (Philips Healthcare, London) and Alistair Piggott (Siemens Healthcare, Camberley) discussed safety aspects of their respective companies’ markedly different approaches to integrating MR with
EXPOSURE LIMITS

Jonathan Ashmore (Guy’s and St Thomas’ Hospital, London) investigated the inconsistencies and ambiguities of predicted and measured SAR (figure 2). These values – on which the MR operator depends in order to scan certain implants safely – are calculated and reported differently and with varying detail by each of the major scanner manufacturers. This raises questions on the reliability of extrapolating MR conditions from the scanner used in testing an implant to clinical scanning with a different manufacturer. The speaker’s ‘wish-list’ requested harmonisation of SAR estimation among vendors, and comprehensive reporting of SAR values. Ideally when scanning an implant, an MR operator would be permitted to impose a preset SAR limit at the outset of the scan.

In contending that peripheral nerve stimulation (PNS), not magnetophosphenes, should inform a preset SAR limit at the outset of the scan. Management of MR-PET suites requires adherence not only to the established safety requirements of each modality, but also to a range of new concerns arising from their joint sitting. For example, the MR-PET scan room requires both an RF cage to keep interfering signals out and lead shielding to keep annihilation photons in, which presents significant logistical difficulties during construction. Standard positioning for PET/CT scans directs the patient to clasp their hands above their heads – this creates a closed loop which may cause induced current burns during MR scanning. While bearing this in mind, the MR-PET radiographer must ensure that coil placement can be carried out while minimising their own exposure – and that an ‘MR conditional’ dosimeter is on hand to ensure they do so!

GUIDANCE DOCUMENTS AND SAFETY INSPECTIONS

Throughout the meeting focus was returned to the general management and policing of MR safety. The official UK guidance document on MR safety has been supplied by the Medicines and Healthcare products Regulatory Agency (MHRA) – and its prior incarnations – since the early 1990s. David Grainger (MHRA, London) outlined the general roles of the agency in licensing, enforcing regulations and monitoring adverse incidents. Recent trends show that changes in the dispensation of gadolinium contrast agents appear to have reduced the incidence of nephrogenic systemic fibrosis (NSF) to virtually zero. The number of MR adverse incidents reported in the UK has been in decline since around 2002. This is out of step with US figures which continue to rise. The talk led into a discussion – chaired by Dan Wilson and John Thornton (National Hospital for Neurology and Neurosurgery, London) on the role of the MR Safety Advisor.

Safety inspections have been carried out in a number of UK MR departments by the Health and Safety Executive (HSE). J. Arwel Barrett (HSE, Bootle) touched on aspects of MR safety on which inspectors may focus, and revealed that future inspections will target departments deemed to be underperforming as opposed to random selection. Barrie Condon (Institute of Neurological Sciences, Glasgow) gave an alternative view, recounting his department’s recent experience of inspection. He stated that in general the inspectors were reasonable in their requests and non-dogmatic. He suggested that in preparing for such an inspection it should be ensured that training documentation, emergency protocols and risk assessments are in place. A few other ‘hostages to fortune’ were flagged up, wherein a disparity may exist between an inspector’s expectation and the practical limitations of staffing levels, availability of information and avenues of communication.

FEEDBACK

Feedback from attendees confirmed that the content of the meeting was considered very high quality, and of great practical benefit in meeting the evolving challenges of MR safety. Personally, I greatly appreciated the opportunity to hear from expert voices in the field and would consider future conferences essential for all those with MR safety responsibilities.
**FIGURE 2.**
Time-varying SAR during a routine brain scan (courtesy J. Ashmore).

**FIGURE 3.**
Early experiments in phosphene stimulation: (a) Jacques-Arsène d’Arsonval (on the right, with assistants) demonstrating bio-effects of alternating current in 1896; (b) the magnetic coils of Magnusson & Stevens (1911) (courtesy D. McRobbie).
IMPACT ON MEDICAL SECTOR OF NEW DOSE LIMITS

DELPHINE DARIO

ROYAL INSTITUTION, LONDON 8th February 2012

IN APRIL 2011 THE INTERNATIONAL COMMISSION on Radiological Protection (ICRP) published a statement in which they recommended a reduction of the radiation dose limit to the lens of the eye. The new recommended limit was set at 20 mSv/y representing a significant dose reduction (more than seven times) from the previous value of 150 mSv/y and has therefore triggered considerable debate in the radiation protection community.

In order to discuss the proposed change on the eye dose limit and its implication on the medical sector, the Society for Radiological Protection (SRP) organised a one-day conference at the Royal Institution of Great Britain in central London entitled ‘Impact on the Medical Sector of Revised Dose Limit for the Eye’ on 8th February 2012. The one-day meeting, which was chaired by Claire-Louise Chapple (Newcastle Upon Tyne NHS Foundation Trust) and Jill Reay (Aurora Health Physics Service Ltd, Oxford), gathered an audience of 80 delegates from both the medical and nuclear sectors. At the end of the morning and afternoon sessions members of the audience were welcome to ask questions to the various speakers and debate some of the issues regarding future legislation and the practical implementation of the new eye dose limit.

SCIENTIFIC EVIDENCE

The opening lecture by Liz Ainsbury (Health Protection Agency, Chilton), entitled ‘Scientific evidence regarding cataract formation: radiobiology and epidemiology’, set the scene for the whole day. She first gave an introduction to the radiobiology of cataract formation. She then presented recent epidemiological studies to discuss whether cataract formation follows a deterministic or stochastic mechanism; it appears that although it was originally classified as a deterministic mechanism in the 1980s, it may actually have a stochastic component. Animal studies have demonstrated that there is a strong genetic component associated with cataract formation and that radiation may speed the process of cataract development. Some human studies have shown that there is a dose threshold (~0.5 Gy) above which the risk of cataract formation increases. Such scientific evidence is in agreement with the early classification of a deterministic mechanism. However, new analysis of the atomic bomb survivors shows that cataract formation could be a stochastic mechanism, i.e. no dose threshold. A number of human studies have shown that there is a dose threshold to the lens of the eye needed to be re-assessed and that further investigation was required to establish whether cataract formation is governed by a deterministic or stochastic mechanism. Her talk was followed by a joint presentation from Hani El-Sabbahy and Mike Nettleton (Health and Safety Executive, Bootle). This talk focussed on the UK’s response to the change in eye dose limit (revision of the UK legislation). Dave Sutton (Ninewells Hospital, Dundee) spoke to us about the dosimetric quantities and their adequacy to determine the eye dose.

We also heard from John Cooper (Health Protection Agency, Chilton) who is part of ICRP. He discussed the position of the ICRP regarding the reduction of the dose limit to the lens of the eye. He explained that before taking the decision to recommend a reduction of the dose limit to the lens of the eye, the ICRP set up a task group to review the scientific literature and produce a report. He also mentioned that the threshold level of 20 mSv/y had not been chosen by chance but was fully considered and chosen to be in agreement with the ICRP definition of a dose threshold which is ‘the dose resulting in only 1 per cent incidence of specified tissue or organ reactions’. Chris Englefield (President of SRP) also gave a brief talk summarising the position of the SRP. He explained that many physicists do not fully support the new dose limit; they argue that it does not represent the same level of risk as the 20 mSv/y whole body dose limit. He also talked about the lack of accurate scientific evidence on the subject, especially regarding the dosimetry, and he briefly discussed the implementation issues that the medical sector is facing. In his conclusion he acknowledged that the dose limit to the lens of the eye needed to be revised but that it may have been done hastily.

IMPLEMENTATION ISSUES REGARDING THE NEW LIMIT

After lunch we heard several interesting talks on the implementation issues regarding the new eye dose limit. Sharan Packer (Bradford Teaching Hospitals NHS Foundation Trust) did an interactive talk to discuss who should be monitored in the medical sector and what the practical issues are regarding the implementation of the new eye dose limit (classification of workers, compliance, cost, multiple employer, etc.). Colin Martin (NHS Greater Glasgow and Clyde, Glasgow) talked about the practical implementation of eye dosimetry. He presented a method to carry out risk assessments in order to identify the workers who need to be monitored. He also introduced a proposal on how to perform eye dosimetry in the UK.

We also had the opportunity to hear from Jonathan Hopkins (University of Birmingham), an Interventional Radiologist. He highlighted the lack of awareness of the dose limits on the clinical side but mentioned that registrars seem to be more aware of the risks associated with ionising radiation. He also gave some suggestions on how to improve compliance with the use of control
measures. For example, in his view compliance regarding the use of lead glasses would be improved if each clinician had their own pair.

The final talk of the day was given by Dave Rawlings (Newcastle Hospitals NHS Foundation Trust). This talk gave an overview of the measures available to reduce the eye dose in practice. He focussed on the training, dose monitoring and radiation shielding devices that are currently available.

Although no ground-breaking new solutions to implement the new eye dose limit were presented, the meeting was useful and very interesting. In my opinion the two discussions held at the end of each session were very fruitful. It gave the attendees the opportunity to discuss legal and practical issues associated with the implementation of the new eye dose limit. I am sure that all of the delegates ended the day feeling more informed about this new development in radiation protection.

IT NETWORKS INCORPORATING MEDICAL DEVICES AND SOFTWARE

RICHARD TROUNCER  Royal Marsden Hospital

BERLIN, GERMANY 1st–2nd March 2012

Medical software and devices that are purchased in the UK are CE marked, having been through a rigorous risk analysis and management process. Unfortunately, if these devices are attached to a network, there is no guarantee that the device will function as it was intended – for instance, a virus may disable the device, insufficient bandwidth may stop data being transferred and, at worst, network storms may disable all medical treatment using the network.

IEC 80001-1,1 published in October last year, attempts to address that deficit. It is the first in a series of international standards intended to help those connecting medical devices to their networks to manage the risk involved.

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IMRT QA and in vivo dosimetry

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No equipment on the patient is required for pre-treatment QA, enabling you to perform IVD on every patient, with no impact on workflow or throughput.

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It comes from two different branches of standards – the medical branch that sees risk in terms of patient safety and efficacy, and the IT branch which sees risk in terms of service and security. As a result, it recognises the need for, and sometimes the tensions between, safety, efficacy and security.

Risk management tries not to just classify risk but also to manage it in a wider context. If a network switch fails, a scanner may be rendered useless. But rather than just classify and quantify this risk, risk management attempts to mitigate it, perhaps with a redundant switch, to ensure that the scanner can continue to work seamlessly.

**Creating a New Role**

IEC 80001 defines a new role, the Medical IT Network Risk Manager. Without this position, it is unclear who is responsible when a medical device is connected to a network, or when problems occur with medical devices already on the network. Attempting to manage the tension between the different perspectives of the medical, technical and IT groups, along with safety, efficacy and security, is a particularly complex task. Although some medical physicists or engineers may have the appropriate skills, this is likely to be a minority, and new training for people taking on the role will be required.

This role has to be appointed by the top management in an institution in a similar way to information governance roles. Incumbents will need to be managed independently from the groups they will be working with, probably as part of risk management departments, with direction from top management. In most cases they will be working with multiple staff groups (medics, physicists/engineers, device manufacturers and IT network staff). Appropriately assessing already existing networks with hundreds of medical devices (and potentially thousands of others) is almost impossible. The problem must be broken up and individual systems analysed in isolation. Such modularisation can help manage risk too – dividing networks into separate smaller networks (physically or via VLANs) can reduce the risk of network storms or the spreading of viruses.

All of this requires resources, both financial, from management and between staff groups, which is likely to be hard to obtain in the current economic environment. But with the number and complexity of networked devices increasing, and ever greater dependence on networks, taking action may be a cheaper option than doing nothing at all. Losing connectivity can stop work for days and will affect patient treatments.

**Conference On Implementation In A Hospital**

The symposium I attended in Berlin, organised by the VDE Institute, was intended to help translate the sometimes arcane language of IEC 80001 into something that can be implemented in a hospital. It was well attended by Germans and Americans with a smattering of other Europeans and some from further afield. The American perspective appeared to lean more towards the legalistic and financial side. Some thought that by convincing the management that not implementing the standard could lead to expensive litigation, resources to implement IEC 80001 would be released, ultimately benefitting patients. Medical device manufacturers (MDMs) were also heavily in attendance. They were all too aware of the problems their devices experienced on hospital networks and were understandably keen to see the risk appreciated, and mitigated, by hospitals. There were also a number of organisations hoping to provide training and services to hospitals wanting to implement the new standard. It is also worth noting that there was considerable discussion as to how ‘software as a medical device’ and interestingly ‘mobile apps’ should be classified. US experts are pushing for all health IT software being classified as ‘Class I with special exemptions’, whereas currently the EU have published guidelines stating that computer systems that are storing, transferring and displaying (but not manipulating) data are not classified as medical devices.

IEC 80001-1 is the first of an evolving family of standards. Many talks focussed on implementations which will probably become part of the standard, from manufacturer questionnaires to detailed documentation. Some of this will form future IEC standards, and will inform revisions of the current standard. There are four volumes which are to be published shortly – IEC 80001-2-1 through 4, covering practical applications and examples, implementations, manufacturer’s disclosures and wireless networks. Hopefully these should make the high-level IEC 80001-1 easier to apply.

The previous NHS standard, ISB 160, now superseded by ISO 80001, was intended to address some of the risks of deploying medical devices. ISO 80001 places a greater emphasis on the network element, and with the recognition of the tensions between the different staff groups and priorities, making it potentially more useful.

**Why Should I Care?**

An obvious question behind much of this is ‘Why should I care?’. Decisions for managing networking risks are usually going to be taken at a much higher level of management than most of us will achieve and have enough problems preserving our own department budgets without creating more posts to eat up precious resources. My personal answer to this would be: ‘Because it is needed – to reduce risks, to ensure the quality of service and to comply with best practice’. The current lack of clear responsibility for managing risk on medical IT networks leaves us potentially providing an inferior service and risks adversely affecting patients. Though people may be making intelligent decisions for managing risk on an informal basis there is no guarantee that this is done, or done properly. Without advocates, like medical physics and engineering departments, pushing for best practice we may not see risks for patients reduced. By encouraging practical adoption of this standard we will be seeking best practice, which will ultimately benefit both us and patients.

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1 IEC 80001-1: Application of Risk Management for IT networks incorporating Medical Devices: Part 1: Roles, Responsibilities and Activities
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<td>Paul Kirkby</td>
<td>Head of Clinical Engineering</td>
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<tr>
<td>Matthew Robert Myatt</td>
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Ireland’s University Hospital Galway Uses Elekta’s Clarity® 3D Ultrasound to Guide Prostate Cancer Radiotherapy

Soft tissue imaging with 3D ultrasound both at therapy simulation and just before treatment has transformed prostate radiotherapy at University Hospital Galway (UHG). Most radiotherapy patients with prostate cancer who visit the clinic will benefit from technology that can accurately track the prostate’s position before each treatment. The Elekta Clarity® 3D system provides ultrasound-assisted image guidance to radiation therapy (IGRT), and avoids the additional radiation dose that comes with other IGRT techniques.

“The big advantage of Clarity is you’re not adding any radiation dose – you’re getting pictures of the prostate for free,” says Margaret Moore, UHG’s Head of Radiation Physics. “For planning treatments, CT simulation and Clarity are a great combination. Both modalities add their bit of intelligence to create the certainty that you’re seeing the target.”

Reliably localizing the prostate is critical as its position can change due to bladder and rectal filling, and patient breathing, she adds.

“If you aim the treatment beams at the same spot every day, but the anatomy you want to treat is moving in and out of the spot, then it’s not getting the full dose it should,” Ms. Moore explains. "Clarity allows us to track the prostate's position before each treatment, and keep the treatment beam on target.” UHG acquired Clarity in 2008 and began using it with one of its three radiation treatment systems. Clarity is capable of integrating with any external beam radiation therapy workflow and equipment to support simulation, planning and treatment.

“In the equipment evaluation, we liked the idea of matching the planning ultrasound to the treatment room ultrasound that Clarity offered,” Ms. Moore says. “Other similar IGRT options try to match ultrasound to CT, which could affect alignment accuracy. Clarity also wouldn’t require reconfiguring our linear accelerator – we could integrate the system easily.”

Versatile Clarity
Radiation oncologists at UHG have been able to use Clarity routinely to fine tune prostate contouring, superficially at the bladder junction.

“In some cases, the lobes of the prostate reach up to the bladder, so distinguishing bladder tissue from prostate tissue is difficult using CT,” Ms. Moore observes. “On ultrasound, there’s a huge difference. The bladder is much more distinctive than the prosthetic gland.”

Remote scanning guides prostate therapy
Clarity’s soft tissue visualization system now provides an Autoscan® option for automated ultrasound scanning from outside of the treatment room, employing a motorized probe positioned at the patient’s perineum. The transperineal approach also benefits planning by providing a clear view of the prostate and surrounding critical areas, such as the penile bulb, thought to be responsible for erectile function. Clearly visualizing these pelvic structures could enable physicians to create plans with tighter margins around intended targets, thus avoiding exposure to uninvolved tissues, including the penile bulbus.

Clarity with Autoscan provides a flexible alternative to traditional hand-held scanning and is the ideal platform on which to build future live (i.e., real time) imaging applications that will track the prostate and surrounding anatomy during treatment*. Live imaging has become increasingly important for physicians who want to pursue reduced margin hypofractionated therapy.

Clinicians at Fletcher Allen Health Care (FAHIC, Burlington, Vt.) who have been evaluating Clarity with Autoscan in clinical trials are excited about Elekta’s latest innovation for soft-tissue imaging in radiation therapy.

“In our experience, patients have found transperineal scanning to be more comfortable than transabdominal ultrasound, because it doesn’t require pressing the ultrasound probe on a full bladder,” says FAHIC radiation oncologist James Wallace, M.D. "The images we acquire truly are remarkable and the therapists say setup is very user-friendly. In addition, we are excited to begin assessing the impact of real-time Autoscan, which will enable us to use Clarity to track prostate motion in real-time during treatment, facilitating on the fly adjustments to patient position.”

*Not yet available in all markets
**Works in progress and not available for sale or distribution.

For more information please visit: www.elekta.com/clarity

Experience the Elekta Difference
Welcome to this year’s summer issue of Scope ‘Book Reviews’. I present you with seven reviews, most from the medical physics genre. A list of the reviewed titles with reviewers can be found below in table 1.

As with each Scope issue, there are a number of new medical physics texts in the ‘Just Published’ section. You will also find some interesting reports listed in the ‘New Reports’ section, such as the AAPM TG-166 report on the use and QA of biologically related models for treatment planning. Reader(s) interested in reviewing listed / unlisted books or even any one of the new reports, please do get in touch with me and I will get the publisher to send you the required material. Note that some of the new reports are freely available to download from the respective websites.

Last but not least, a warm welcome to three new book reviewers:

- **Ruth Picknett-Powell** – trainee Clinical Technologist (Healthcare Science Practitioner) specialising in radiotherapy physics, based at the University Hospital Southampton NHS Foundation Trust.
- **Julie Wooldridge** – trainee Clinical Scientist specialising in clinical engineering and electrodiagnostics, based at the University Hospitals of Leicester NHS Trust.
- **Lisa Davenport** – Clinical Scientist specialising in radiation protection, based at the St Luke’s Hospital (part of Bradford Teaching Hospitals NHS Foundation Trust).

We still require more book reviewers to hit our new target of eight book reviews per quarter, so please do join us! [The Ubidesk book reviewing team]

**Usman I. Lula** (usman.lula@poole.nhs.uk)

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### TABLE 1

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**Radiobiology for the Radiologist**

Radiobiology for the Radiologist is not, as its title states, just for radiologists – anyone who works with medical applications of ionising radiation will appreciate this excellent reference. Now in its seventh edition, this latest version is in full colour and has many relevant up-to-date revisions and additions to make it an appropriate reference for today, including sections on nuclear terrorism and retreatment with radiotherapy.

It is essentially two books in one, with half given over to the study of radiobiology and all its clinical applications (including radiology and nuclear medicine), and the second half focussing entirely on radiotherapy. For this reason students of radiotherapy professions and radiotherapy departments will benefit most from this book; however, the scope is general enough to be of use to any medical discipline which involves ionising radiation.

It is very well structured with each chapter following the same basic format. The first half reads very much like a set of radiobiology course notes, following the principles of radiobiology from basic physical principals right through to biological outcomes. The authors themselves thank their students from years of radiobiology classes, so this is perhaps not surprising, and certainly students will find that this book complements their studies very well.

The second half lends itself to the radiotherapy clinic. Radiobiological experiments are explained with many diagrams and examples and there are also chapters dedicated to modalities other than photons (including protons and carbon ions) and a chapter on the effects of hyperthermia on radiosensitivity.

As a quick reference in the planning room it has some merit too, as it contains very nice tables including a summary of tissue tolerances as published in the QUANTEC report, and a few worked examples of calculating effective doses for different fractionation regimes.

As well as everything you would expect to find in a radiobiology textbook this has some additional chapters on topics which are rarely mentioned in other books. The small chapter on retreatment with radiotherapy is very welcome. Although it remains vague in its recommendations it is nice to see an attempt to address this issue, and it makes some good points. I am sure that in future versions this section will become increasingly weighty as more clinical data is acquired. There is also a chapter about the interaction of chemotherapy agents with radiotherapy, including a 17-page table of chemotherapeutic drugs summarising how they work, what they are used for and how they might interact with radiotherapy. As someone with a physics background whose education does not include any details on chemotherapy agents I found this to be an interesting resource.

There is even a chapter on radiologic terrorism, discussing some possible scenarios and how to manage patients that are victims of such an attack. An interesting addition, but hopefully one I won’t ever have to refer to.

Overall, the book is easy to read and presents the topic in interesting, and at
times fun ways. I would recommend this book to students of radiobiology and to radiotherapy planning departments.

Ms Keri Owen is a Principal Clinical Scientist at the Queen Alexandra Hospital in Portsmouth, UK

RADIOBIOLOGY FOR THE RADIOLOGIST
Edition: Seventh
Authors: Eric J. Hall and Amato J. Giaccia
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Computed Radiation Imaging: Physics and Mathematics of Forward and Inverse Problems

This 302-page hardback describes the physics and mathematics of computed imaging methods. These cover any imaging that requires some computation to be carried out on the measurements before an image can be produced, such as computed tomography, PET and tomosynthesis. The book is split into two parts; the first considers the physical interactions that take place between the radiation and the object being imaged. This is referred to as the forward problem.

Mathematical models are built to represent radiation transport and measurement for transmission, emission and scatter-based situations, including a derivation of the Beer-Lambert law and Boltzmann’s transport equation. The second part of the book details methods of image reconstruction, the inverse problem. Analytical Fourier-based methods, iterative techniques and probabilistic solutions are all covered. Chapters are self-contained, with references at the end of each. However, there is little cross-referencing between chapters, and the lack of an index makes searching through the book more difficult than it should be.

Elsevier say that an index is included in the electronic version, but I think that it would have been far more useful in this print edition.

I found the content to be highly mathematical, and was often left wishing for more diagrams to illustrate the points being made. However, this may simply be a reflection of my rusty maths. The book contains occasional grammatical errors, such as the use of the word convoluted instead of convolved. There are some omissions, such as the absence of fluorine-18 from the list of common PET isotopes. This particular oversight may be due to the author’s background in mechanical engineering. The text is well referenced, with the author often referring the reader to another publication for a detailed explanation of a concept that is relied upon in the book. However, I feel this leaves the publication short of being a self-contained reference on image formation and reconstruction.

The book is pitched at graduate students and researchers. I wouldn’t recommend this as a departmental purchase, but it may be relevant to individuals carrying out postgraduate research in imaging.

Mr David Platten is a Clinical Scientist in Diagnostic Radiology at the Medical Physics Department of Northampton General Hospital, Northampton, UK

Handbook of Breast MRI

Sub-speciality MRI textbooks tend to present themselves in two forms: the over 500 page multi-author, sometimes multi-editor, hardback that will cover everything from A to Z and the more condensed, but practical, softback. The former usually represent the absolute reference and give a full detailed picture of the subject at the time they are published. However, the nature of such works makes them less likely to be updated regularly. (Incidentally, they also look good on your shelves but might make you scream for a Kindle edition every time you use them.)

In breast MRI, the current leader in the heavyweight category is Breast MRI: Diagnosis and Intervention edited by Elizabeth Morris and Laura Liberman whereas titles like Breast MRI: Fundamentals and Technical Aspects by R. Edward Hendrick or Breast MRI in Practice by Alan Coulthard and Ruth Warren compete on the softback market.

Handbook of Breast MRI is a new addition to the more condensed approach. Its author, Jeremy Price, is a radiologist with a particular interest in breast MRI and its use as a screening tool. The book is divided into eight self-contained chapters that are not dissimilar to small review articles on each sub-subject and includes the now de rigueur end-of-chapter exercises.

The first chapter is a basic summary of the usefulness of breast MRI with some even more basic technical sections. Although not that relevant to physicists, it sets the tone of the book for its primary audience, radiologists and oncologists. The second chapter is dedicated to breast anatomy and pathology and, along with the glossary and various appendices, it is an invaluable source of information for non-clinicians. Despite their short length, the next six chapters provide in-depth coverage of current clinical applications, from general study interpretation (Chapter 3) and more in-depth problem solving (Chapter 7), to biopsies (Chapter 4), screening (Chapter 5), staging (Chapter 6) and implants (Chapter 8).

Obviously, not everything can be covered in 20 to 40 pages but the essential is always there and the more avid reader can quickly find further details for specific problems thanks to the extensive reference list.

One difficulty with shorter textbooks is to distil the essence of a large subject without losing its substance. On the whole, Jeremy Price did manage this very well. Although the book is primarily targeted at radiologists and oncologists with an interest in breast MRI, due to its condensed nature they might consider it to be just as an introduction or a quick reference guide. However, I really think it is an excellent textbook for any MR physicist or radiographer as it provides a lot of information on the current protocols.
In short, Handbook of Breast MRI is a very useful and well-written book that deserves to find a place on the shelves of any MR scanner control room.

Dr Marc E. Miquel is a Lead MRI Physicist at the Barts and the London NHS Trust

Overall, the papers were interesting, contained great technical detail and were well illustrated (both in colour and black and white) with appropriate graphs, tables, diagrams, equations and photos to illustrate the points being made. Each paper had extensive references to support the text. The last two papers, however, did feel a little out of place. The Supercollider: The Texas Days is the second of two articles describing the history of the Superconducting Super Collider in Texas and follows on from the first article published in the first volume of this series. I am unsure about its relevance to the ‘medical applications’ in the title and haven’t read the first instalment in Volume 1. A Man for All Seasons: Robert W. Wilson is a factual but also anecdotal biography of the founding director of the Fermi National Accelerator Laboratory, USA, which is of interest for its historical background. Both of these papers are entirely different to the preceding more rigorous scientific papers.

For me, there were two main detractors when reading this text. Firstly, there was a significant amount of overlap between papers, presumably due to multiple authors writing papers in very similar areas. However, this does mean that there is no need to read the articles sequentially, instead individual papers can be selected according to need or interest. Secondly, as I have not worked in this field, I found the abundance of acronyms overwhelming. I would have welcomed a glossary to which I could quickly refer when either an acronym had not been explained, or I had forgotten it since its introduction in the preceding pages. The papers were generally well written, though I did find a small number of typos or strange syntax. Although I think this volume may have felt a little out of place. The Supercollider: The Texas Days is the second of two articles describing the history of the Superconducting Super Collider in Texas and follows on from the first article published in the first volume of this series. I am unsure about its relevance to the ‘medical applications’ in the title and haven’t read the first instalment in Volume 1. A Man for All Seasons: Robert W. Wilson is a factual but also anecdotal biography of the founding director of the Fermi National Accelerator Laboratory, USA, which is of interest for its historical background. Both of these papers are entirely different to the preceding more rigorous scientific papers.

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Recent Advances in Biomedical Ultrasound Imaging Techniques

Rather than a typical book, this takes the form of an issue of the journal *Interface Focus*, published by Royal Society Publishing, and aims to give an up-to-date overview of contemporary ultrasound research in biomedical ultrasound imaging techniques. It sits nicely between the various textbooks available that cover the fundamentals of ultrasound imaging physics and the numerous journal papers on ultrasound research. This issue of the journal is made up of 14 review papers from several well-known authors, many of whom are based in the UK.

I especially enjoyed reading the article relating to ‘Quantitative contrast-enhanced ultrasound (CEUS) imaging’. The article describes the sources of variability in quantification of CEUS such as the effects of blood pressure on bubble properties, the setup of the ultrasound scanner controls as well as the type of bubble agent itself.

Two other papers that attracted my attention were ‘Biomedical photoacoustic imaging’ and ‘Ultrasound-mediated optical tomography’ (also known as acousto-photonnic, not to be confused with photoacoustic!). This first technique (acousto-photonnic) uses laser pulses to generate transient heating, which causes pressure changes in the tissue resulting in generation of low-amplitude ultrasound waves that can be detected at the skin surface. As light is more readily absorbed by haemoglobin, lipids and water so causing local heating, this technique has leant itself to developments in, for example, imaging of the microcirculation or plaque characterisation in coronary arteries. The second technique, ultrasound-mediated optical tomography, uses ultrasound to modulate the local refractive index and the position of the optical scatterers hence modulating the phase of the photons that pass through the insoned region, the idea being that it may be possible to measure the optical absorption properties from a specific region of tissue determined by the ultrasound beam. Among the other interesting topics covered are:

- Developments in vector velocity imaging, which can demonstrate the complex nature of blood flow.
- An overview of 3D ultrasound scanning.
- Continuous wave ultrasonic Doppler tomography.
- Ultrasound image analysis and image-guided intervention.

The series of papers concludes with an article reviewing the laboratory and epidemiological current evidence on the safety of diagnostic ultrasound.

This journal consists of 220 pages with 14 extensively referenced review papers, making this a useful source of information. This journal would be of interest to scientists and engineers wishing to expand their knowledge of current ultrasound research or who are new to this field and about to embark on an ultrasound research project. In my estimation, this represents good value for money in a time when many journals are reducing the number of good value for money in a time when many libraries are reducing the number of journals readily accessible.

*Ms Abigail Thrush is a Clinical Scientist in Vascular Ultrasound (Clinical Physics) at the Barts and London NHS Trust, UK*

**Recent Advances in Biomedical Ultrasound Imaging Techniques**

*Organised by:* Hai-Dong Lai, J, Alison Noble and Peter N.T. Wells

*Journal, Publisher:* Interface Focus, Royal Society Publishing

*Reference:* Volume 1, Issue 4, pages 475–697, 6th August 2011

*Price:* £49
The book is divided into sections dealing with the fundamentals of diagnostic accuracy, regression, agreement, modelling with an imperfect reference standard and verification bias. The book closes with chapters on determination of optimal result thresholds (e.g., what level of abnormality in a medical image is sufficient to make a diagnosis?).

Just Published!

**Physics for Clinical Oncology** by Amen Sibtain, Andrew Morgan and Niall MacDougall (Oxford University Press) is the first book on radiation physics written specifically for the needs of the practising oncology team.

**Statistics of Medical Imaging** by Tianhu Lei (Taylor & Francis) covers statistical aspects of imaging technology to the statistical analysis of images. This textbook fills the gap in the literature to provide a unified framework of study.

**Accelerator Physics, 3rd Edition** by S. Y. Lee (World Scientific Publishing) covers the historical accelerator development, transverse betatron motion, synchrotron motion, an introduction to linacs and synchrotron radiation phenomena in low emittance electron storage rings.

**Computational Modelling of Biological Systems** by Nikolay Dokhoyan (Springer) provides an overview of emerging computational methods for modelling biologically and medically relevant systems. It describes multiple methods for modelling, visualising and rationally altering systems at various length scales.

**Biological and Medical Sensor Technologies** by Krzysztof Iniewski (Taylor & Francis) presents contributions from top experts who explore the developments and implementation of sensors for various applications used in medicine and biology.

**Physics in Anaesthesia, Oxon Edition** by Ben Middleton, Simon Stacey, Rik Thomas and Justin Philips (Scion Publishing) provides an overview of emerging technologies, modelling prior to using it on their own data. It may, however, be viewed equally as a weakness if the reader is unfamiliar with the software. A brief introduction is provided but it does not really represent sufficient instruction. However, the core audience should have no problems picking things up, particularly as the WinBUGS website provides plenty of practical assistance.

Without question, this book achieves its stated aim. Whilst it is not suited to the amateur, practising statisticians involved in medical research will find plenty here to expand their analytical repertoire, particularly if they already use WinBUGS (or its open-source variant, OpenBUGS). Highly recommended, therefore, but to a specific audience.

Dr James Stirrup is a Clinical Research Fellow in Cardiac Imaging at the National Heart and Lung Institute, Imperial College, London. He is also a Cardiology Specialist Registrar at the Wessex Deanery, UK.

**Advanced Bayesian Methods for Medical Test Accuracy**

Series: Chapman and Hall/CRC Biostatistics

Author: Lyle D. Broemeling

Publisher: CRC Press


Pages: 487

Price: £84.55 (Amazon UK)

**BOOK REVIEWS**

**SCOPE**

**New Reports**


The name Fick is familiar to all students of physiology. The Fick principle remains one of the standard methods by which cardiac output may be measured, calculated from the difference in blood oxygen concentration between the pulmonary and systemic arteries and the measured oxygen consumption rate. The man who introduced this technique to experimental physiology in 1870 was Adolf Fick, when he was Professor of Physiology in Würzburg. In the paper’s introduction he said: ‘It is astonishing that no one has arrived at the following obvious method by which the amount of blood ejected by the ventricle of the heart with each systole may be determined directly…’. The work was presented to the Würzburg Physical and Medical Society. Those interested in chance meetings may like to know that Wilhelm Röntgen was a member of this Society at the same time, whilst working as August Kundt’s young assistant. Twenty-five years later he would make the first announcement of his new kind of rays to the same Würzburg Society.

Fick’s principle, now widely taught, was at that time a quite minor contribution in comparison with Fick’s other work. However, he commands a place in the history of medical physics, not primarily for the wealth of his contributions to physiology, important though they are, but for his first book, *Die medizinische Physik*, published in 1856. Before speaking of this book, however, a brief background should be given to developments in physiology in Germany at that time.

**Hermann von Helmholtz (1821–1894)**

Science flowered in German universities during the second half of the nineteenth century, and in no discipline more so than physiology. A group of outstanding scientists emerged (figure 1), all dedicated to the principle that the biological sciences should be subject to the same rigours of experimental study and analysis as had become established for physics and chemistry. The dominant member of this group was Hermann von Helmholtz, a physicist by inclination and ultimate reputation, a doctor by training, an enthusiast for the free market approach of German universities, and who made profound contributions in electrodynamics, energetics, hydrodynamics, epistemology and, of particular interest here, in sensory physiology. His father was a poorly paid teacher of philosophy, with a keen interest in art and music. Hermann was the oldest of four children. There were insufficient funds for him to study physics at university, as he would have wished. Instead he turned to medicine, for which government
support was available, subject to a commitment to work as an army surgeon following graduation. He studied in Berlin, where he met several older, but like-minded, students, including Emil du Bois-Reymond (1818–1896). They utterly rejected a physiology based on the existence of a vital life force, a view still held by their teacher, Johannes Müller (1801–1858), and instead set out to base physiology explicitly and exclusively on the laws of physics and chemistry.

Helmholtz gained his MD in 1842, and then spent 5 years back in his home town of Potsdam as an army surgeon. It was during his subsequent appointment as Associate Professor of Physiology at Königsberg that his talents started to become more widely recognised. In 1851, he demonstrated his ophthalmoscope (figure 2), an instrument that allowed the study of the retina by viewing the patient’s eye through an axial aperture in an illuminated concave mirror. At a time when diagnostic instruments were no more sophisticated than a stethoscope and a pocket watch to time the pulse, some doctors viewed this new instrument with suspicion. One declared that it was unsafe to shine light directly into the eye; another that the ophthalmoscope might be useful for a physician with bad eyes; his, however, were good, so he had no need of it.

His next appointment, as Professor of Physiology at Heidelberg (1858–1871), was highly productive. He revived and developed Thomas Young’s three-colour theory of colour vision, including it in his three-volumed *Handbook of Physiological Optics*. In 1862 he published the first edition of his *Sensations of Tone as a Physiological Basis of Music*, a deeply influential text on physiological acoustics. After leaving Heidelberg he moved on from physiology, gaining the prestigious Chair of Physics in Berlin, where he spent his remaining years, becoming patriarch of German science and the state’s foremost scientific advisor. He had an international presence, and formed lasting friendships with various English physicists, notably William Thompson, later Lord Kelvin.

**NERVE CONDUCTION VELOCITY**

In 1850, whilst still at Königsberg, Helmholtz had carried out an experiment which lies more comfortably associated with the life of his friend and colleague, Emil du Bois-Reymond: he measured the nerve conduction velocity.

Unlike Helmholtz, du Bois-Reymond was a specialist, and worked particularly on electrophysiology. His strict father, from Switzerland, was a teacher in Berlin. His French mother ensured that her native language was normally spoken at home. He studied physiology under Müller, graduating in 1843, presenting a review of electric fishes, which became the root of his lifelong work in bioelectricity. During the next few years he demonstrated nerve current for the first time, using a highly sensitive multi-turn galvanometer that he built himself. His background led him to seek contact with French scientists. He visited Paris in 1850, where his work was evaluated by a commission from the Academy, which included the physiologist Magendie and physicists A-C Becquerel and Claude Pouillet (see below). They were not wholeheartedly enthusiastic, and du Bois-Reymond returned to Germany feeling rather disappointed by what he felt to be French scientific isolationism. He later spoke to a more receptive audience at the Royal Institution in London.

At that time, it was believed that the nerve impulse was transmitted instantaneously, but this seemed contrary to his new understanding of nerve electricity. Helmholtz rose to the measurement challenge, and adapted a method first reported in Paris in 1842 by Pouillet, to determine the speed at which a bullet travels. Pouillet’s method used a galvanometer in transient mode, a constant current being applied to the coil during a period very much less than the natural period of oscillation. The experiment is shown in figure 3. On making the contact $S$, the nerve is excited at $e$, and simultaneously a voltage is applied to the galvanometer $R$. The needle starts moving. Following nerve conduction and a latent period, the muscle contracts and switch $nN$ opens, ending the current flow through the galvanometer coil. The time-period is then determined from the needle displacement. By repeating the experiment and applying the stimulus to several points along the nerve, Helmholtz showed that there was a delay associated with nerve conduction, reporting a conduction velocity of $26.4\, \text{m}\, \text{s}^{-1}$.

**ADOLF EUGEN FICK (1829–1901)**

Born in Kassel, Germany, in 1829, Adolf Fick was the youngest son of a senior city architect of a Protestant family. He was a student in the nearby old university town of Marburg, where he intended to study mathematics. Guided instead into medicine by his brother, the professor of anatomy there, he came under the influence of Carl Ludwig (1816–1895), a close friend of du Bois-Reymond. Ludwig recognised his talents, supervising his first paper in 1849, an investigation of the torque exerted by the muscles of the femur on the hip joint. Both men then left Marburg. Fick to continue his studies in Berlin and Ludwig to become Professor of Anatomy and Physiology at Zurich. Letters between du Bois-Reymond and Ludwig show these two creative scientists eying up Fick’s career potential. Ludwig sent a letter of recommendation, penned as a poem, which Fick delivered on his arrival in Berlin in October 1849. Du Bois-Reymond approved: ‘Fick is an excellent fellow … destined to become an organic physicist’. Six months later, Ludwig expresses concern: ‘Draw (Fick) away from so-called practical medical matters … Also keep an eye on his considerable indolence’. Du Bois-Reymond agrees: ‘Fick’s work is a little masterpiece. Unfortunately … (he is) as much a genius at dawdling as ever. I fear that he will not turn his tremendous … talents to account’. Fick returned to Marburg in 1851 to complete his degree, presenting a thesis on visual errors due to astigmatism (echoing Thomas Young’s early career, half a century earlier). In spite of du Bois-Reymond’s concerns, Ludwig however continued to believe in Fick’s talents, and appointed him as Prosector (demonstrator) in Anatomy in Zurich, where he started at Easter 1852.

**DIFFUSION**

After his arrival in Zurich, Fick continued to carry out studies in...
biomechanics and physiological optics. But Ludwig was now interested in diffusion, and believed that Fick's mathematical skills could crack the problem. Three years later, Fick published his work.³ He noted the absence of a single law for diffusion, and announces modestly in the introduction to his paper, 'I have endeavoured to supply this omission'. Here, Fick demonstrates his true colours. He may have been educated as a doctor and employed in an anatomy department, but he had the mind and knowledge of a physicist. He recognised the strong analogy between diffusion and the conduction of electricity and heat, and postulated that it might be described using the same formalism as that used by Fourier for heat, or Ohm for electricity. He thus proposed for the first time a formulation giving the flux $\frac{\partial y}{\partial t}$ proportional to its concentration gradient $\frac{\partial^2 y}{\partial x^2}$, with a constant of proportionality $k$, the diffusion constant. Experimental confirmation was challenging, requiring the measurement of varying concentration with position. Fick's successful verification used two reservoirs containing water and saline, linked with different lengths of tube.

**DIE MEDIZINISCHE PHYSIK**

By now, Fick was marked as being an outstanding young talent, completely aligned with the new thinking of physics in physiology. Still in his mid-twenties, he accepted an invitation from the publishers of Müller-Pouillet's book **Lehrbuch der Physik** to write a supplement on medical physics.

This proposal was highly innovative, and worth considering further. Claude Pouillet (1790–1868) had succeeded Dulong as Professor of Physics in Paris in 1838, and had earlier (1827) published a highly popular physics textbook.⁴ In 1842, the physicist Johann H. J. Müller (1809–1895) translated and published a German edition of Pouillet's textbook, which he later extended to create a popular German version, published under their joint names. It is unclear whose initiative created the invitation to Fick to write a supplement on medical physics. Certainly Pouillet was quite familiar with the subject, still ill-defined in Germany, having worked earlier with Pierre Pelletan in Paris. Equally, Fick's name could have been suggested by Ludwig (credited as a collaborator in the introduction); or it may simply have been an inspired proposal from the Brunswick publishers, Veiveg and Son.

In his introduction, Fick claims that the book is 'a first attempt to introduce between physics and physiology (or if one prefers, the whole of medicine) a physiological or medical physics'. Fick then carefully states that the concept of such a discipline is not his own. Generally, he prefers to use the term 'physiological physics'. The title page (figure 4) makes clear that doctors (Mediziner) were the target audience. I wonder what the editors thought when the script arrived. The text they read was definitely not a physics textbook for medical students, similar to those of Pelletan or Golding Bird. It was a detailed description of contemporary concepts of physics applied to problems in physiology. Fick used calculus deliberately, partly because he viewed it as unavoidable, and partly in an attempt ‘to dispel a widely-held prejudice that infinitesimal calculus is beyond ordinary comprehension’. Nevertheless, the book remained popular, presumably mostly amongst academic physiologists. Its third and final edition was published in 1885. **Die medizinische Physik** has eight chapters, each one including Fick’s own personal contributions. He placed his latest work on diffusion in the first chapter. This is followed by one on skeletal mechanics, including his work on the physics of muscle contraction. There follows a chapter on haemodynamics including wave motion in elastic tubes and the work of the heart. His chapter on sound includes not only speech production, but also respiratory and circulatory acoustic sources. In ‘Heat’ he focuses on the chemical origins of heat in the body, and on heat in disease. ‘Optics’ enables him to review his own contributions on astigmatism, accommodation and colour vision. In the final chapter he deals with the electricity of nerves and muscles, in which he largely draws on the work of du Bois-Reymond. It was perhaps only here, when presenting work of a trusted colleague rather his own, that history would show the analysis to be in error. Du Bois-Reymond was a brilliant experimentalist, but had convinced himself that the tiny electrical currents he measured from damaged muscles were also active in vivo. His analysis, which Fick reproduces, gives a detailed but erroneous description of muscular electricity as arising from arrays of spherical ‘peripolar’ molecular units, with a positive charge at the equator and negative charges at the poles.

The eighth chapter is in some ways the most interesting. The philosophy of the German school of physiology was to learn by observation and measurement. In Chapter 8, Fick described nine instruments for physiological measurement: planimeter, Ludwig’s kymograph (figure 5), sphygmograph, microscope, Helmholtz’ ophthalmoscope (figure 2 and chronometer (figure 3), stereoscope, du Bois-Reymond’s galvanometer (figure 6) and induction apparatus. But, unlike other authors, he not only described the instruments, but analyses their performance. For instance, his section on the kymograph for recording the blood pressure wave includes a mathematical discussion, accompanied by illustrative waveforms, of the interaction between the driving and resonant frequencies. And the careful analysis of the astatic galvanometer shows how to stabilise this exquisitely sensitive instrument.

**FICK’S LATER LIFE**

Fick married in 1862, before settling in Würzburg in 1868 as Professor of Physiology. Once there, he demonstrated that he was as skilled a practical experimentalist as he was in applying mathematics to physiology. He is credited with developing the first plethysmograph (1869), the first contact lens (1887), the first successful ophthalmometer (1888) and a dynanometer in 1891. He constructed a model of the arterial tree using rigid and elastic tubes of varying diameters to simulate the pressure drop in the circulation (1888).

The majority of Fick’s work was reported in German publications. One report, however, appeared in English⁵ and came about because of a family connection. The English chemist Edward Frankland.

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1. **FIGURE 2.** (TOP LEFT) The Helmholtz ophthalmoscope.
2. **FIGURE 3.** (TOP RIGHT) Apparatus used by Helmholtz to measure nerve conduction velocity.
3. **FIGURE 4.** (MIDDLE LEFT) Title page from Fick’s *Die medizinische Physik* (detail).
4. **FIGURE 5.** (MIDDLE RIGHT) Ludwig’s kymograph for blood pressure measurement.
5. **FIGURE 6.** (BOTTOM LEFT) The astatic multiplier galvanometer.
...power that powered the muscle was muscle protein itself. To Frankland and Fick this appeared illogical. In the autumn of 1865, with his colleague Johannes Wislicinus, Fick carried out an experiment to test Liebig’s theory. They climbed 1956 m to the top of Mount Foulhorn in Switzerland whilst on a protein-free diet. During the climb, they collected all their urine for measurement of the excreted nitrogen, and showed that the energy which could have been generated from the associated protein fuel was less than half that required to climb against gravity. It remained to Frankland to complete a very careful series of calorimetric experiments to finally demonstrate Liebig’s error.

Fick died in Belgium on 21st August 1901. In spite of the astonishing range of his contributions to physiological physics, his passing remained unmarked in Britain for almost a year, when an obituary appeared in *Nature*. The 19th year, when an obituary appeared in *Nature*. The 19th century, the foundations of modern physiology were established.

**SUBSEQUENT MEDICAL PHYSICS IN GERMANY**

Fick’s *Die medizinische Physik* served as the foundation stone on which medical physics could slowly gain purchase in Germany. First to follow was Wilhelm Wundt (1832–1920). He gained a medical degree from Heidelberg in 1856 and, 2 years later, became assistant to the newly arrived Professor of Physiology, Hermann Helmholtz. Wundt gained inspiration from Helmholtz in the study of sensory physiology and epistemology (the philosophical study of knowledge), and went on to found a new discipline of physiological psychology. He was a prodigious writer, and his *Handbuch der medizinischen Physik,* published in 1867, was but one of an extensive list of publications during his long career, on philosophy, psychology, physiology and physics. Poorly illustrated, it must have been a challenge to use. Nevertheless, it gained a new life when later translated into French by Ferdinand Monoyer, Professor of Medical Physics at Lyon, and embellished with numerous illustrations.

One other author, Theodor Hoh (1828–1888), published his *Die Physik in der Medizin* in 1875, when he was a lecturer in mathematics and physics in Bamberg. He had studied medicine in Würzburg, graduating in 1853, with a thesis on the human effects of imponderable fluids (that is, light, heat, electricity and magnetism). He later abandoned medicine to become a high-school physics teacher.

**THE LEGACY OF FICK AND HELMHOLTZ**

Hermann Helmholtz dominated the German, and to a certain extent the international, scientific stage during the latter part of the nineteenth century. His contributions to physics applied to physiology, and in particular to sensory physiology in optics and acoustics, are widely recognised. By comparison, Adolf Fick was much less flamboyant, travelled little and was far less known outside his native Germany. Yet his book, the first wide-ranging book to use the title ‘Medical Physics’, set a benchmark for physics applied to physiology, defining the depth and breadth of this new discipline. Whilst his book was never translated from its original German, later authors structured their own books around his framework, and this new literature helped to encourage a steady diffusion of physics into physiology, and hence into medicine.

**ACKNOWLEDGEMENTS**

I am particularly grateful to Dr Dan Wolverson, physicist and linguist, who translated key passages from the gothic German script of *Die medizinische Physik.*

**ABOUT THE AUTHOR**

Francis Duck is Honorary Consultant Medical Physicist in the Department of Medical Physics and Bioengineering at the Royal United Hospital Bath NHS Trust and visiting professor at the University of Bath.

Email: f.duck@bath.ac.uk

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**REFERENCES**


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