Correcting interruptions in radiotherapy treatment

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Half a century Celebrating in Edinburgh

P08 QA MAKES TRIAL STRONGER
Evidence-based medicine in radiation therapy for clinical trials

P21 ULTRASOUND MEASURING
Using an ultrasound method to estimate muscle volume in vivo

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The incident according to the Daily Express in January 1984
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Innovation, innovation

Peter Jarritt suggests that innovation is happening throughout the healthcare system and encourages forward thinking in research.

It is hard to ignore the message that ‘innovation’ is the only method by which the health service will be sustainable into the future. NHS England has propounded the Innovation, Health and Wealth agenda linking the country’s economic success to innovation in health. This has resulted in large sums of money being invested to support this agenda including agencies aimed at supporting the innovators and the commercialisation of their ideas. All the major science and technology grant funding bodies have a large proportion of their funds dedicated to health-related topics. Network concepts have proliferated within the health community seeking to bring together health professionals, academics and technology companies to deliver on this agenda. Furthermore commercial and consulting companies now hover around the health community seeking to capture ideas and funding in a way never seen before. The health community seeks to collaborate to minimise the economic hardship that many institutions face. Finding a way through this landscape is often a daunting problem for the hospital-based clinical scientist, whether physicist or engineer, and yet I do believe that they are well placed to meet the challenge of the innovation agenda. With colleagues the ‘unmet clinical need’ can be identified and possible solutions taken from idea to prototype. The expertise on how to take an idea from the academic laboratory to the patient bedside often resides within our community and is often overlooked and not understood by our academic colleagues. A number of departments have in place quality systems and resources that allow them to design, manufacture and CE mark products for use with patients. Scaling up from ‘one bedside’ to ‘many beds’ or implementing ideas within a wider community is often much more challenging and will often require significant investment. It is clear many ideas never make it to the marketplace because they are not seen as ‘commercially viable’. In the patient arena and in the age of personalised medicine I do not believe this should be seen as an impediment to the development of ideas and products as opposed to profit.

This year sees the 7th anniversary of the formation of the National Institute for Health Research (NIHR). With resources aimed at supporting research and innovation within the health community there is every opportunity for all healthcare scientists to link to key research initiatives and to seek funding for novel ideas. In addition, funding to undertake PhD programmes post qualification is regularly available and should not be overlooked by newly qualified clinical scientists.

Health Technology Co-operatives

The NIHR has recently funded the development of eight Health Technology Co-operatives. These have been built upon two successful pilots, one of which has been ‘Devices for Dignity (D4D)’ run by Wendy Tindale. The chosen themes address areas of high morbidity and unmet need for NHS patients and healthcare technology users. These co-operatives have funding for 4 years commencing January 2013. One of their primary aims is to act as a catalyst for the development of new medical devices, healthcare technologies and technology-dependent interventions. They are charged with bringing partners together to develop, test and improve product concepts leading to clinical evaluation and demonstrated patient benefit. The key areas include brain injury, trauma management including rehabilitation, cardiovascular disease, devices for dignity, colorectal therapies and wound prevention and treatment. IPEM members are involved in a number of these programmes and I would encourage anyone with an idea to contact a relevant group to gain advice and even seek funding to demonstrate proof of concept. Local circumstances and infrastructure should not be an impediment to gaining advice and support on taking an idea forward. Further information can be found at www.nihr.ac.uk/infrastructure/Pages/HTCs.aspx.

As healthcare scientists at all levels our potential lies in our ability to further apply science and engineering for the benefit of patients. We cannot and should not be content with the status quo. The IPEM will again this year invest £50,000 to support the pump priming of novel research and provide yet another opportunity for members to take forward their ideas.

In closing I want to encourage you to attend the ICMP conference from 1st to 4th September 2013 in Brighton. This will form the IPEM Annual Conference for 2013 as well as the European and IOMP conferences for 2013. This is a rare opportunity to participate in an international medical physics and clinical engineering conference without leaving the UK. Registration and further details are available at www.icmp2013.org.uk.
The Final Report of the Independent Enquiry into Care Provided by Mid Staffordshire NHS Foundation Trust (known as the ‘Francis Report’), published in February 2013, contains recommendations that have implications for all professionals working in healthcare. Some of these recommendations are specifically for professional organisations, and some are aimed at registered professionals. So it was important for IPEM to review these recommendations on behalf of members, and to draw out actions relevant to us as an organisation, and to members as individuals.

I know that our members are committed to high standards of practice and conduct

The Professional Advisory Group (PAG) discussed the relevant recommendations at its meeting in March, and reported back to Council. The areas most relevant to IPEM members are about providing leadership, setting standards for conduct and practice, measuring quality and reporting concerns. PAG’s conclusions were that many of the actions proposed for professional organisations were already being undertaken by IPEM, but that these need to be highlighted and, in some cases, updated for the benefit of members. Specifically:

- There is guidance on conduct and practice for IPEM members from the Institute’s own Code of Conduct, the Code of Conduct for registrants on the Voluntary Register of Clinical Technologists, HCPC standards for registered scientists and the Good Scientific Practice document adopted by the Academy for Healthcare Science. These documents have all been made more easily accessible via the IPEM website.
- There are IPEM policy statements available via the website which set evidence-based standards for procedures, interventions and pathways. Some of these are now due to be updated – this has been highlighted on the website.

and a programme for review is underway. In addition, IPEM is currently in discussion with the Department of Health about producing a new set of service accreditation standards for both medical physics and clinical engineering, for the Academy of Healthcare Science. We need to recognise this work as an example of how we ensure the quality and safety of services, in line with our strategic objectives.

- As members’ employing organisations have in place procedures for reporting concerns, PAG felt that IPEM’s role is to signpost to these, and to organisations which can offer direct support to individuals who are fearful of the consequences of such reporting. We will put further information about such organisations on our website for members.
- PAG made the point that, post-Francis, professional engagement in quality and developmental activities must be actively encouraged and facilitated by all concerned; whereas at present it is increasingly difficult for members to be released for this. We will repeat our call for this to the Department of Health and others, which rely on volunteer input to achieve their aims, but could do more to mandate this with the NHS and other employers.
- The recommendation to identify the qualities of a good and effective leader is being taken forward through our work with the Royal College of Radiologists on the design of the Higher Specialist Scientific Training (HSST) programme; we will continue to contribute to this. The competencies required for leadership by scientists are also present in Good Scientific Practice, and we have extracted these and posted them in a separate document on the website.

The Government will be issuing a fuller response to the Francis Report in the autumn, and we will review this for any further actions. We will also continue to discuss this important report with other professional bodies, including the Royal College of Radiologists and Society and College of Radiography, to identify any issues on which we should take joint action.

I know that our members are committed to high standards of practice and conduct and I hope that these actions will provide them with additional support and guidance to deliver this.
Crowd sourcing

Welcome to the summer edition of Scope! You may notice some interesting new changes this issue. We’ve relocated some of the meeting reports to the website to enable us to create more space for you! We may not all work at CERN or have played the bongos with Brian Cox but if you’ve got an interesting tale to tell, we’d like to hear it!

We’ve made the room and we want you to fill it. Whether it’s sharing observations about bad science that you’ve read, or reminiscing about misreported accidents at work (see below), we’d appreciate your contribution.

Scope is the perfect forum for general interest articles, good research that might not necessarily be suitable for a journal, reports on collaborations and projects, trainee projects, historical features, tutorials and other pieces that would engage the interest of the membership.

Support is available for all budding authors. It is always nice to see your views on what you’ve read in Scope! Whether you support or disagree with someone’s viewpoint we want to hear from you.

And on to this edition. Michael Dolan and David Gow lead us on a historical journey through 50 years of bioengineering in Edinburgh. Page 28 introduces us to an initiative which aims to improve the maintenance and management of medical equipment in developing countries. We will be following the progress of this worthwhile and fascinating project in subsequent editions. Also in this issue the highly regarded physicist Jack Fowler describes strategies to correct for interruptions in radiotherapy treatments, a must read for all radiotherapy physicists. We round off with ‘Covering-up a great atom leak: tabloid scare stories’ by W. Alan Jennings, a tabloid scandal from the 1980s.

I hope that you may be inspired to contribute to Scope either as feedback or an article, but if not, I hope you enjoy reading it as much as I do!

Whether you support or disagree with someone’s viewpoint we want to hear from you

GEMMA WHITELAW EDITOR-IN-CHIEF
Improving detection of myocardial ischaemia

CARDIAC IMAGING

Researchers at Massachusetts General Hospital (MGH) have developed a new reconstruction algorithm that reduces two significant sources of artifact in cardiac PET scans, and could significantly improve the detection of myocardial ischaemia. In a study the algorithm demonstrated up to 235 per cent greater sensitivity than conventional reconstruction approaches.

Movement of the heart through both the cardiac and respiratory cycles and the partial volume effect (PVE) are two significant sources of PET image degradation. Cardiac motion produces blurring and attenuation artifacts, whereas PVE smears photon counts around the true location of tracer uptake.

Cardiac gating is one method of reducing motion artifacts, but the extraction of counts from individual cardiac phases and rejection of counts from other phases results in a low signal-to-noise ratio (SNR). Alternatively, motion-corrected PET identifies counts from each location in the myocardium over all cardiac phases, combining them in a single image with a significantly higher SNR. The team at MGH used the latter approach, correcting for motion using tagged MRI, acquired simultaneously with PET data on a hybrid PET/MRI scanner.

The motion data were incorporated into the system matrix of an existing list-mode PET ordered subset expectation maximisation (OSEM) reconstruction algorithm. The system matrix models the count acquisition process and by incorporating the MRI-derived motion data, the model accuracy is improved, as is the quality of the reconstructed image.

PVE artifacts were reduced by incorporating a model of the detector’s point spread function (PSF) – the detector’s response to a point radioactive source – into the system matrix. The modified matrix acts like an iterative deconvolution process during image reconstruction, filtering out the detector response from the reconstructed image and improving image resolution.

The modified algorithm was tested against gated and non-motion-corrected PET using a deformable phantom that simulated cardiac motion, and areas of ischaemia and reduced perfusion. Qualitative improvements in perfusion defect visibility were clear, particularly when PET and MRI images were fused. SNRs were used to quantify lesion detectability. Imaging using the new MRI motion correction outperformed other approaches convincingly, by 115–136 per cent compared with gated imaging and by 62–235 per cent compared with non-motion-corrected imaging over three lesion sizes. When the PSF model was included in the reconstruction algorithm, lesion detectability increased by a further 39–56 per cent.

In ongoing work, the researchers have extended the algorithm to correct for respiratory motion and are testing it in vivo in animal models and patients.

MORE INFORMATION
This paper was published in Phys Med Biol 2013; 58: 2085.
http://dx.doi.org/10.1088/0031-9155/58/7/2085

Intra-fractional volumetric imaging

IMAGE-GUIDED RADIOTHERAPY

Researchers at Stanford University in California have used a new cone-beam CT (CBCT) technique to image soft tissue anatomy in a lung cancer patient during respiratory gated volumetric-modulated arc therapy (VMAT). Using a relatively small number of kilovoltage (kV) x-ray projections and a non-standard reconstruction algorithm the technique has potential applications that include treatment delivery verification and the reporting of cumulative dose.

Using an on-board imager, 20 to 40 projections are acquired from a 360-degree arc around the patient during treatment. Using a smaller number of projections than is typical for conventional CBCT, dose to the patient is limited. The respiratory gating signal triggers both the kV projection and the megavoltage (MV) treatment beam, with the image data being acquired immediately prior to delivery of the treatment beam. This approach achieves intra-fractional imaging while avoiding any contamination of the images with scatter from the MV treatment beam.

The researchers developed a new reconstruction algorithm to compensate for the undersampling of the patient anatomy compared to conventional CBCT. The fast iterative shrinkage/thresholding algorithm with line search (FISTA-LS) is a fast first-order algorithm that uses a compressed sensing approach which is effective at reconstructing images from sparsely sampled data.

The technique was used to image a thoracic phantom that mimicked respiration and one lung cancer patient receiving VMAT treatment. Images generated using the FISTA-LS algorithm were compared to those reconstructed with a Feldkamp–Davis–Kress (FDK) algorithm, as used for conventional CBCT reconstruction.

Soft tissue structures could be discerned in the images produced by this technique. The FISTA-LS algorithm performed better than the conventional FDK algorithm, which produced significant streaking artifacts in both the phantom image (figure 1) and the patient image (figure 2).

Quantitative comparison using a contrast-to-noise ratio (CNR), a measure of the treatment target contrast compared to the image background, revealed that images generated using the FISTA-LS algorithm had a target contrast two to three times greater than the FDK algorithm.

The researchers are now investigating ways to improve in vivo image quality. A clinical evaluation on a larger patient cohort is also being planned.

MORE INFORMATION
This paper was published in Med Phys 2013; 40: 040701.
http://dx.doi.org/10.1088/0031-9155/40/4/040701

Figure 1. Superior images of a thoracic phantom were obtained with the FISTA-LS reconstruction (right) algorithm compared to the conventional FDK algorithm (left)

Figure 2. Image quality was lower in the in vivo images, though the FISTA-LS algorithm (right) still performed better than the FDK algorithm (left)
QA makes a radiotherapy clinical trial stronger: evidence-based medicine

**Recent RT trials have become more comprehensive and labour intensive requiring substantial human and financial resources. QA is necessary to ensure treatment is safely and effectively administered. QA warrants that the uncertainty in the dose delivered to the patient, associated with each step in the process of tumour delineation, treatment planning, including data transfer and RT delivery within a prospective trial, is kept reasonably low and that the RT deviations will not corrupt the overall results of the trial.**

This systematic review by Weber et al. assesses the impact of RT protocol-deviations on a patient’s outcome in prospective phase II–III RT trials and the necessity of performing QA within prospective clinical trials.

Fifty-five studies were identified using popular databases and these studies were filtered further to exclude items such as review papers, guidelines, audits and meta-analysis to nine eligible phase II–III studies to be used for this systematic review. For this review, prospective QA analysis or intervention QA review was defined by any review of the patient-specific QA data performed before the end of the first week of RT. In prospective QA analysis, feedback from the QA team was given back to the institutions to recommend modification of the treatment, should the plan be non-compliant. Revised plans were subsequently further assessed and, if necessary, additional changes recommended.

**RT deviations were rated into those in which the deviations were predicted to have a major adverse effect on tumour control probability, toxicity or both from those that might be considered to be compatible with a reasonable standard of care (table 1, opposite). The rates of RT major deviations in prospective trials are substantial, ranging from 11 per cent to 48 per cent (table 2, opposite). The number of accrued patients per centre has been significantly associated with the quality of the delivered RT within a prospective protocol, with a cut-off ranging from 10 to 20.**

In one large phase III trial of advanced head and neck cancers performed in 81 centres using prospective and interventional QA, the estimated local-regional failure and overall survival were similar for those patients with compliant RT plans *ab initio* and those plans made compliant by the interventional QA review.

Of all the studies assessing the impact of protocol delinquency on quality of RT, five studies undisturbedly show that non-adherence to protocol-specified RT requirements do have a detrimental impact on a patient’s outcome. Effect on outcome has been found to be associated with reduced survival, local control and potentially increased toxicity. Non-protocol compliant RT in clinical trials may waste time, effort and money and could, more importantly, harm patients. The rate of major deviation can be substantially improved with the implementation of prospective and intervention QA approaches.

**MORE INFORMATION**

This work was published in the Green Journal. Radiother Oncol 2012; 105: 4–8. [http://dx.doi.org/10.1016/j. radonc.2012.08.008](http://dx.doi.org/10.1016/j.radonc.2012.08.008)

**Editor’s note:** National and international trials involving RT require detailed implementation by an MPE and draw on resources of the general RT staffing. The initial set-up and maintenance of clinical trials is estimated as one WTE clinical scientist required for every eight clinical trials (IPM, 2009) though this does depend on the complexity of each trial and the extent of physics input. Refer also to the recent Review Article in the BJR (86), 2013, titled ‘Improving radiotherapy quality assurance in clinical trials: assessment of target volume delineation of the pre-accrual benchmark case’, presented on behalf of the NCRI RTTQA Outlining and Imaging Subgroup. This article addresses methods to reduce interobserver variation in clinical trials and how to conduct an assessment of outlining through a pre-accrual benchmark case.

**ADDITIVE MANUFACTURE**

Production of complex multi-pinhole SPECT collimators can be labour intensive, expensive or sometimes impossible. Researchers have examined a rapid collimator construction technique called metal additive manufacturing, which involves building up the collimator in layers, using selective laser melting of tungsten powders at locations defined by the CAD design file as solid material [Med Phys 40: 012501].

**COMPACT X-RAY SOURCE**

A team has invented a compact radiation source that could be used to create low-cost, portable x-ray scanners. The device uses a piezoelectric crystal (lithium niobate) to produce more than 100,000 V of electricity from only 10 V of electrical input. Such low power consumption could allow it to be fuelled by batteries [IEEE Trans Plasma Sci 41: 106].
### TABLE 1

<table>
<thead>
<tr>
<th>Study [ref.]</th>
<th>Years of randomisation</th>
<th>Major deviations (tumour)</th>
<th>Major deviations (normal tissues)</th>
</tr>
</thead>
<tbody>
<tr>
<td>HD 4 [5]</td>
<td>1988–1993</td>
<td>• Excessive or incomplete tumour coverage by radiation</td>
<td>ND</td>
</tr>
<tr>
<td>HD 7 [9]</td>
<td>1994–1998</td>
<td>• Total dose &lt;90% or &gt;110% of the prescribed dose</td>
<td>ND</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Technical deficiency</td>
<td>ND</td>
</tr>
<tr>
<td>RTOG 0411 [4]</td>
<td>2005–2006</td>
<td>• 90% isodose surface not encompassing the planning target volume</td>
<td>ND</td>
</tr>
<tr>
<td>RTOG 9704 [1]</td>
<td>1998–2002</td>
<td>• Total delivered dose of ±10% of the prescribed randomised dose</td>
<td>ND</td>
</tr>
<tr>
<td>RTOG 0022 [8]</td>
<td>2001–2005</td>
<td>• Overall treatment time exceeding the normal treatment time by 10%</td>
<td>ND</td>
</tr>
</tbody>
</table>

### Table 1: Dosimetric definitions of major deviations for QART performed in prospective trials. © Elsevier, ‘QA makes a clinical trial stronger: evidence-based medicine in radiation therapy’, Damien C. Weber, Milan Tomsej, Christos Melidis and Coen W. Hurkman; Radiother Oncol 2012; 105: 4–8

### TABLE 2

<table>
<thead>
<tr>
<th>Study [ref.]</th>
<th>Type of QA</th>
<th>Number of cases evaluated n (%)</th>
<th>Minor deviations n (%)</th>
<th>Major deviations n (%)</th>
<th>Technical issues with QA review n (%)</th>
<th>Impact on clinical outcome</th>
<th>p value</th>
</tr>
</thead>
<tbody>
<tr>
<td>HD 4 [5]</td>
<td>R</td>
<td>368 (98.0)</td>
<td>–</td>
<td>141 (37.5)*</td>
<td>8 (2.1)</td>
<td>7-year RFS with D: 72%</td>
<td>0.004</td>
</tr>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>vs 7-year RFS without D: 84%</td>
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<td></td>
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<td>5-year RFS with D: 90%</td>
<td>0.31</td>
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<td></td>
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<td>vs 5-year RFS without D:84%</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Grade GI ≥ 3 toxicity with D: 45%†</td>
<td>0.05</td>
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<tr>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td>vs Grade GI ≥ 3 toxicity without D: 18%†</td>
<td></td>
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<td></td>
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<td></td>
<td></td>
<td>mOS with D: 1.46 yo</td>
<td>0.008</td>
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<td></td>
<td></td>
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<td>vs mOS without D: 1.74 yo</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td>LRF with major D: 50%</td>
<td>0.04</td>
</tr>
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<td></td>
<td>vs LRF with no major D: 6%</td>
<td>&lt;0.001</td>
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<td>OS with major D: 70%</td>
<td></td>
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<tr>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td>vs OS without major D: 50%</td>
<td></td>
</tr>
</tbody>
</table>

Abbreviations: R, retrospective; P, prospective; LRF, local-regional failures; D, deviations; mOS, median overall survival; RFS, relapse-free survival; GI, gastrointestinal; NS, not specified.
* Deviations were scored as adherence per protocol or less than per protocol (see main text for details).
† Deviations were scored as adherence to protocol-defined volumes, dosimetry, treatment time and technical delivery characteristics (see main text for details).
‡ Denominator is influenced by the number of patients with negative clinical outcome and/or the absence of delivered RT (see main text for details).
†† QA of the TROG study was performed with a primary (interventional) prospective review and secondary review. Figures provided in the table are from the second retrospective review.
* Deviation from chemotherapy regimen.
** Number of evaluated cases in the interventional prospective QA programme.

Elekta’s Versa HD™ System Sets New Standard of Radiotherapy for Cancer Patients Worldwide

During a live global event on March 1, Elekta announced the launch of Versa HD™, an advanced linear accelerator system designed to improve patient care and treat a broader spectrum of cancers. Featuring highly conformal beam shaping and tumour targeting, Versa HD also introduces new capabilities designed to maximize health care system resources and deliver highly sophisticated therapies without compromising treatment times. Elekta has achieved CE Marking, allowing European medical centers to employ Versa HD for their patients with cancer.

Versatility to deliver better treatments to more patients

Versa HD gives clinicians the flexibility to deliver conventional therapies to treat a wide range of tumours throughout the body, while also enabling treatment of highly complex cancers that require extreme targeting precision. As an integrated treatment system, Versa HD offers the versatility to address today’s growing cancer management challenges.

“In Versa HD, we incorporated technologies that would provide an immediate impact to patient health and quality of life,” says Elekta’s President and CEO, Tomas Puusepp. “Versa HD represents another market-leading innovation from Elekta, and reflects the best thinking of Elekta’s technical experts and our clinical partners.”

Integrated with Elekta’s Agility™ 160-leaf multileaf collimator (MLC), Versa HD provides ultra-precise beam shaping – critical for maximizing the dose to the target while also sparing surrounding healthy tissues. Importantly, this high targeting accuracy is available over a large field-of-view, permitting delivery of high-definition (HD) beams to a wide spectrum of complex targets. Historically, high-definition beam shaping often was mechanically limited to only small target therapies. Versa HD with Agility overcomes this challenge, now empowering clinicians to deliver extremely precise beam contouring for both small and large targets.

Unprecedented combination of High Dose Rate delivery and rapid MLC leaf speed

Capable of delivering radiation doses three times faster than previous Elekta linear accelerators, Versa HD harnesses the ultra-fast leaf speeds of Agility MLC. With this groundbreaking combination, clinicians can now – for the first time – fully exploit higher dose rate delivery, potentially enabling even greater capabilities for sophisticated therapies, including stereotactic radiosurgery (SRS), stereotactic radiotherapy (SRT) and volumetric modulated arc therapy (VMAT).

Versa HD™ is not available for sale or distribution in all markets.

For more information please visit: www.VersaHD.com

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www.jicru.oxfordjournals.org

RADIATION PROTECTION DOSIMETRY

RPD publishes peer-reviewed papers covering all aspects of personal and environmental dosimetry and monitoring for both ionising and non-ionising radiations. Visit the journal homepage to purchase special issues dating back to 2000.

www.rpd.oxfordjournals.org
This year marks the 50th anniversary of the establishment of the clinical bioengineering service in Edinburgh and provides an opportunity to review how bioengineering has developed locally. The service officially began on 4th May 1963 and half a century later, what began in a small basement with a narrow remit for a single diagnostic group has blossomed to offer services and devices its founders would never have thought possible.

The purpose of the service as stated in its Annual Report for 1986 still holds true today:

To respond to the problems of patients where adequate solutions are not available within the existing routine clinical services. This may relate to the lack of particular knowledge about their condition and its management or the lack of a suitable device to alleviate their disability… The ultimate objective of all our activities is the improvement of clinical services and our service to the disabled.

The scope of existing routine clinical services has certainly widened in terms of equipment provision as devices that at one time would have been cutting-edge and custom-made are now readily available commercially. The goalposts may, therefore, have shifted but the role of bioengineering at the forefront of providing innovative solutions to complex problems for people with disabilities remains.

This article aims to give an overview of the development and work of the Edinburgh service. It is not possible to cover or even mention all aspects so instead, a few of the more noteworthy areas of work have been selected for detailed coverage. The timeline (figure 1) gives an overview of key events and milestones.

**Origins and early years: 1963 to 1977**

In 1963 funding was provided by the Scottish Home & Health Department to set up a small workshop in a basement in George Square, in close proximity to the Royal Infirmary of Edinburgh and the University of Edinburgh. The Powered Prosthetics Unit, as it was...
The early pioneering work of David Simpson and the unit was recognised by many awards over the years

Originally known, was headed up by Dr (later Professor) David Simpson. It was charged with designing and providing upper limb prostheses for children born with limb abnormalities as a result of the drug thalidomide. Initially, referrals were received from Scotland, Northern Ireland and Eire. This was a particularly difficult beginning due to the prevailing emotive atmosphere of politics and intense media interest. Within the first year, the unit employed four technicians and a deputy director, but due to a growing workload and the need for ongoing research and development it was soon necessary to employ more staff.

In 1965, the unit moved 3.5 miles south to larger premises on the Princess Margaret Rose (PMR) Orthopaedic Hospital site. From a clinical perspective this was the ideal location as it was the principal regional hospital for the treatment of children with ‘disabling musculoskeletal disorders’. To support the work, a Self Care Unit was set up in 1966 to provide residential accommodation (consisting of three bedrooms, a day room, a sitting room and a kitchen) for ‘children with severe limb deficiencies and their mothers’.

In 1967, the unit was renamed the Orthopaedic Bio-Engineering Unit and the Medical Research Council and the Scottish Home & Health Department agreed to provide and equip a new building. This was subsequently opened in 1969 as the Bio-Engineering Centre (the hyphen was mysteriously dropped around 1986). The 325 m² building contained a mechanical workshop, a plastics laboratory and an electronics laboratory as well as clinic rooms and office and storage space. Staffing levels subsequently peaked at around 25 and the focus of its work began to expand to include aids for daily living (such as an IBM electronic typewriter adapted to operate with a switch activated by a shoulder shrug in 1970) and special hospital beds and other large equipment.

The early pioneering work of David Simpson and the unit was recognised by many awards over the years. In 1970 he was awarded the prestigious SG Brown Medal of the Royal Society and appointed Personal Chair of Orthopaedic Bio-Engineering in 1972 by the University of Edinburgh. Professor Simpson was also the President of the Biological Engineering Society (now subsumed in The Institute of Physics and Engineering in Medicine) between 1972 and 1975. In 1977, Professor Simpson resigned as the director to take up a post at the University of Edinburgh.

In the early 1980s the centre established close research links with the Department of Orthopaedic Surgery at the University of Edinburgh in the area of fracture fixation and healing. Later that decade this collaboration saw the successful development of a new cannulated tube saw for epiphysiodesis that was used by local surgeons and manufactured by the centre until the early 2000s.

In June 1984, Thomas Dick was appointed as the third director. One of the effects of the various research and development programmes and ad hoc patient services was that the centre was at this time beginning to accumulate a significant number of patients with a broad range of unusual or difficult physical problems who began to look to the centre for their ongoing care. As a result of this shift in emphasis, in 1987 the decision was made to emphasise the centre’s patient service activities by formalising patient referral procedures and by continuing to develop working relationships with referral sources. Research areas during this period included functional electrical stimulation and topography, as well as a clinical trial of incontinence garments.

In 1988, oversight of the centre was transferred to Lothian Health Board. This was one of the consequences of the Scottish Home and Health Department’s review of Professor Ian McColl’s 1986 UK-wide report on artificial limb and appliance centres. The report also provided a useful lever for research funding to, for example, help the centre to experiment with silicone polymers to improve the strength and durability of cosmetic covers for artificial hands. An umbrella organisation, called Rehabilitation Engineering Service Lothian Area (RESLA) including Bioengineering, Prosthetics and Mobility, was formed and Thomas Dick was appointed its first director with Dr Barry Meadows as Director of Bioengineering. To mark the 25th anniversary of the centre an open day and symposium was held reuniting former staff and patients alike.
In 1989 new office and clinic facilities and an outpatients department for RESLA were opened in an extension on the end of the listed, modernist Clinical Research Unit. Excellent though the facilities were they had one major drawback; the new build was at the entrance of the hospital, but the bioengineering workshop remained in the original centre at the top of a steep hill. Any alterations to equipment or a requirement for items from the store during a clinic appointment necessitated a round trip of nearly half a mile, adding at least 10 minutes to the length of an appointment.

In 1991, Dr Barry Meadows was appointed Director of RESLA. In 1993, David Gow was appointed the Director of RES (the Lothian Area remit being dropped as a consequence of the formation of NHS Trusts) and Ian Loudon as the Head of Bioengineering Services.

On 27th October 1997, the new David Simpson Library was formally opened with a series of invited talks headlined with a presentation from Professor Dudley Childress on ‘What the past tells about the future of limb prosthetics development’, in recognition of Professor Simpson’s seminal work on the control of upper limb prostheses.

Modern times: 2000 to date

The turn of the century marked a shift to a more professionally accountable service. Since October 2000, clinical scientists have been required to be registered with what was then the Council for Professions Supplementary to Medicine and is now the Health and Care Professions Council (HCPC). Of the six permanent bioengineers currently employed, four were ‘grandfathered’ onto the original register (via IPEM’s voluntary register), one obtained registration through Route 2 and one is currently working towards registration via Route 2.

With the opening of the New Royal Infirmary in Edinburgh, the PMR Orthopaedic Hospital closed to inpatients in January 2002. Bioengineering (along with Prosthetics), however, remained on an increasingly desolate site until May that year. The services moved to temporary accommodation at the Eastern General Hospital where it remained for over 5 years. The Eastern General Hospital was also in the process of being closed and, once again, the service was left as the only one operating from the site. The difficulties of operating from this site, in terms of its location and the temporary ad hoc nature of the facilities, made the provision of a regional clinical service additionally challenging.

In December 2006, the Bioengineering and Prosthetics Services moved to their current location in the purpose-built Southeast Mobility & Rehabilitation Technology (SMART) Centre at the Astley Ainslie Hospital (figure 2). The following January they were joined by the Wheelchair Service, Disabled Living Centre and Driving Assessment Service. The 4,000 m² building was officially opened on 26th February 2007 by the Deputy Health Minister Lewis Macdonald. Although Bioengineering has had a somewhat nomadic existence over the years, it has remained within a 3.5 mile radius of its original location.

The Orthotics service moved in to the SMART Centre in July 2011 to join with the existing services. Together these now constitute the SMART Services. It covers the Lothian, Fife and the Borders Health Board areas with Driving Assessment offering a national service.

At present there are six full-time, permanent bioengineers, or clinical scientists, and one Route 1 (Part II) trainee employed at the SMART Centre (figure 3). David Gow is currently the Head of SMART Services. Clinically, bioengineers lead the Seating, Electronic Assistive Technology and Special Needs Design services and provide scientific support and expertise to the Anderson Gait Laboratory, the adult and children’s wheelchair services, and the prosthetic and orthotics services. The workshop consists of six rehabilitation engineering technicians (clinical technologists), four of whom have been with the service for over 25 years. The services provide assessment, provision, clinical follow-up, ongoing equipment repair, maintenance and adaptation as required.

Upper limb prosthetics

The early years of the centre were devoted to the provision of upper limb prosthetics (figures 4, 5 and 6). Initially it served a population of around 60 children, many of whom were followed from birth into young adulthood. The first prosthesis with ‘extended physiological proprioception’ (EPP) was fitted to a child.
Physical aids for the disabled

The 1974 a new internal section was set up – the Medical Research Council Unit for Physical Aids for the Disabled – to protect the powered prosthetic limb programme from being overwhelmed by other work and also to address the obvious and growing local demand for clinical-based design and custom manufacture. An early example, from 1964, was a feeding aid made for a child with arthrogryphosis multiplex congenita (resulting in severely limited upper limb movement). Gas power was used to raise a spoon, fork or cup and two levers were used to rotate the plate and manoeuvre the implement in the horizontal plane to the mouth (figure 8). NHS funding was soon secured with a remit of ‘the design and production of special aids for the handicapped, from beds and seat to wheelchair’.

The requirement for special wheelchair seating grew steadily and to such an extent that it required its own dedicated service. Over the years the section evolved and changed, to become the ‘Specialised Aids for the Disabled’ with two main functions of bespoke clinical provision for individual patients and the long-term development of aids that would benefit large groups and that may eventually be manufactured commercially.

By 2000, the renamed ‘The Special Needs Design Service’ was receiving around 150 referrals annually that resulted in the provision of a device by a full-time clinical bioengineer supported by a full-time technician. Since then, with the increasing availability of commercial assistive devices the service has reduced in size (to around 50 per year) but remains an important source of bespoke solutions for those with complex needs.

Over the years, the nature of the work has been diverse to say the least, from a cot rocking device, reinforcing walking frames, providing night positioning equipment, an adjustable hip spica plaster casting frame, a glowplug cigarette lighter (figure 9), adaptations to allow participation in sports and other leisure activities to customising feeding aids and providing a interface to

> in 1964. It had three movements; elbow flexion, pronation/supination and prehension. This was developed further with the addition of shoulder elevation and circumduction/humeral rotation. The arms were gas powered as opposed to electrically powered because electrical components, such as batteries and motors, were too heavy for practical use at that time. Research and development continued alongside the clinical service, and included the development of a complete adult arm prosthesis with endoskeleton construction and the functioning PMR hand with a cosmetic glove. The development of a child’s hand prosthesis and partial hand prostheses followed.

In 1979/1980, the centre, along with the local prosthetists, were involved in the clinical trial of the Swedish System Teknik hand prosthesis for young children that went on to become routinely used. By the mid 1980s a database on an Apple microcomputer was being used to store patient records. By the time the centre celebrated its 25th anniversary the original patient group were all adults and this aspect of the centre’s work had waned. Research nevertheless continued in the area of upper limb prosthetics, though now electrically powered, and cosmetic gloves.

On 26th August 1998, after 11 years of research and development (with funding from the Scottish Chief Scientist’s Office), the first complete powered electrical arm prosthesis (know as the Edinburgh Modular Arm System [EMAS], figure 7) was fitted at the centre and witnessed by seven television crews and over 30 journalists and photographers from all over the world. The user continued to use the arm for 18 months and worked with the team to develop and improve its functionality, and several other arms were manufactured and fitted to other users. The core component of the arm was a patented powered lever system which was used in 2006/2007 in the so-called ‘International Arm Fittings’ in Chicago, including the world’s first female powered arm wearer.

▶ FIGURE 4. [TOP LEFT] Early mid to late 1960s gas-powered upper limb prosthesis.

▶ FIGURE 5. [BOTTOM RIGHT] Radiograph of a CO2 cylinder used in the upper limb prostheses. A silencer ensured that the sound of the exhaust was inaudible in most circumstances.

▶ FIGURE 6. [BOTTOM LEFT] Passive arm (series II) with gas-powered commercial hand (c1971). CO2 gas bottle is located in the upper arm (regulator not shown).

▶ FIGURE 7. [TOP RIGHT] The Edinburgh Modular Arm System (c1995). Electric-powered arm movements were based on the gas-powered arm work and structure.
allow an upper limb prosthesis user to carry a London 2012 Olympic torch.

Orthopaedic biomechanics
During the 1980s the centre undertook a number of collaborative developments with the Department of Orthopaedic Surgery led by Edward Draper. One project, an investigation into the effect of later fracture shift, led to the design and construction of a bone torsion testing machine. The output from the strain gauge amplifier was sampled using the analogue input of a BBC model B microcomputer which was subsequently used to analyse the resulting data. Another project was to design an external fracture fixation system that would be easier to fit in the operating theatre and allow for both compression and distraction. Work was also carried out on the mathematical modelling of fracture fixators, the mechanical properties of tendon sutures and the feasibility of using foil strain gauges on fracture fixators.

During the mid 1980s a surgical tube saw was designed in cooperation with a local orthopaedic surgeon to improve the technique of epiphysiodesis – the method used to correct moderate, from 2 cm to 5 cm, discrepancies in leg length during childhood. The saw offered significant advantages over other methods: a shorter and less traumatic surgical procedure, a reduced recovery period, no need to immobilise the leg in plaster, and overall superior cosmetic results. The relatively simple equipment (figure 10) was developed over a 10-year period and continued in use for around a further 10 years.

Electronic assistive technology
The need for suitable control systems for electrically powered prostheses (figure 11) and wheelchairs has meant that electronic assistive technology has been at the heart of bioengineering in Edinburgh for many years. In the mid 1980s, research funding was obtained to develop interfaces for tetraplegic patients to access microcomputers with around 15 patients trialling five different input devices.

In the late 1980s the service, in collaboration with the University of Edinburgh’s Communication, Access, Literacy and Learning (CALL) Centre, developed and trialled the ‘smart wheelchair’ with sensors mounted in the front and rear bumpers. It was designed to give children who could not control a conventional powered wheelchair the educational experience of independent mobility. This went on to be further developed by the CALL Centre and was subsequently commercialised and is still available from Smile Rehab Limited (Newbury).

The advent of smaller ventilators and the establishment of an Edinburgh-based home ventilation service in the late 1990s led to the service becoming involved with powering ventilators from wheelchair batteries and manufacturing mounts to carry the ventilators. Newer, more energy-efficient ventilators and better battery technology means that it is no longer necessary to provide power from the wheelchair and the last one was recently taken out of service.

During the late 1980s, the Control Interface Service was formally set up to primarily provide special controls, e.g. a single switch for powered wheelchairs, as well as individually adapted mounts for remote joysticks, controllers, switches and communication aids (figure 12).

Environmental control systems enable very severely disabled people to control electrical equipment such as alarms, pagers, telephones, intercoms and home entertainment equipment. Up until 1997, environmental control systems were funded separately and installed and maintained by commercial contractors. In 1999, Bioengineering took on the installation and maintenance of environmental control systems and since that date all new Lothian installations have been fully fitted and maintained by the in-house team. The resulting savings have allowed many more systems to be provided and currently there are 96 environmental control installations in Lothian. Where appropriate the service also integrates

![FIGURE 8. [LEFT] Gas-powered feeding aid operated by microvalve and levers (1964) shown with spoon. The device was clamped to a table, as shown, or to a wheelchair tray.

![FIGURE 9. [BOTTOM RIGHT] The glowplug cigarette smoking aid (c1997) design for individuals with motor neurone disease or Huntington’s chorea who wished to continue to smoke independently.

![FIGURE 10. [TOP RIGHT] Epiphysiodesis tube saw (c1998). A: Steinmann pin; B: centralising cylinder; C: hollow tube saw; D: threaded end piece; E: T-handled extruder.]
Recently, bioengineers have once again become increasingly involved in research and development in this area with a particular focus on clinical and ISO technical standards and models of service provision.

Clinical gait analysis
The first gait analysis system (consisting of three infra-red cameras, a force platform and an eight-channel EMG) was installed in 1986 for research and teaching purposes in the hospital’s physiotherapy gym. Subsequently, when the laboratory was relocated into its own space (within the main hospital building), the laboratory was named the Anderson Gait Laboratory after the James and Grace Anderson Trust in recognition of their support and generous funding of research. It was formally opened by the Scottish rugby international Gavin Hastings on 8th November 1995. The clinical gait analysis service, like many other aspects of the centre’s current work, started as research and development and gradually progressed into a routine clinical service with recurrent NHS funding secured in 1996 (figure 14). The laboratory has a highly successful research record with a particular focus on the clinical relevance of gait analysis in children with cerebral palsy, but has also published widely on the characterisation of normal gait in children and the development of the Edinburgh Visual Gait Score. Indeed, gait analysis accounts for around 25 of the 85 or so peer-reviewed journal articles that have been published on the centre’s work.

Today, the gait analysis system consists of six high-definition infra-red cameras, two force platforms and a 16-channel wireless EMG and is staffed by a highly experienced, multi-disciplinary team with particular expertise in cerebral palsy.

Commercialisation
The benefit to the wider population of people with disabilities of commercialising devices developed by the service appears to have been recognised very early in the
Summary

Over the past 50 years the Edinburgh service has evolved and adapted to suit the demands of its stakeholders and technological and societal developments and challenges. Some areas of research and development, such as the Simpson-Edinburgh Airbed, have passed into the mainstream and would, quite rightly, no longer be considered to require specialist clinical bioengineering input.

Some areas have waxed and waned as demands of referrers and the priorities of research funders have changed. All clinical services have become subject to increasing scrutiny and regulation. The Medical Devices Directive is paramount in this regard as all custom-made devices must meet the essential requirements for patient safety. Bioengineers themselves have evolved into HCPC registered clinical scientists with all the requirements that come with modern health professional regulation.

Although this article is specifically about the Edinburgh service, little can be achieved in science and technology without collaboration and in this respect, Edinburgh is no exception. Indeed, the service was established following a visit to Professor Ernst Marquardt in Heidelberg, Germany, and many significant areas of work have been carried out with the help of and in collaboration with other services. In Scotland these include the Dundee-based Tayside Orthopaedic and Rehabilitation Technology Centre (e.g. gait analysis and wheelchair seating), the University of Strathclyde’s Bioengineering Unit (which is also celebrating its 50th anniversary) and, of course, various departments of the Edinburgh-based universities.

It would, perhaps, be foolish to predict how clinical bioengineering in Edinburgh will develop and change over the next half a century, beyond saying that the service will not go far wrong if it remains true to its pioneering spirit of innovation and the application of technology for the clinical benefit of its patients.
To correct for interruptions in radiotherapy treatments

Jack Fowler [University of Wisconsin, Madison, USA] describes methods to correct for missed treatment days during radiotherapy, calculating advantages and disadvantages

There is much evidence on the detrimental effect on tumour control of missed treatment days during radiotherapy. ‘The mean loss of 1.6 per cent per day of prolongation in local control in head and neck cancer (range 0.4–2.5 per cent) has been well recorded...’ This is the first publication that raised this problem quantitatively. Another way of expressing the same loss rate is as loss of ‘treatment dose per day’, which is 0.6 Gy (in terms of 2 Gy fractions = EQD), also called the K factor. It is lower for slower-growing tumours. Even in the slowest tumours (e.g. prostate) it can reach about half that rate (K = 0.25 Gy/d) (Howard Thames, but only after 50 days of radiotherapy, his cut-point). Cervical and uterine cancer can repopulate at half the head and neck rate (K = 0.4 Gy/d; 0.2–0.7), probably starting from an earlier cut-time than 50 days. The most rapidly repopulating tumours include head and neck, lung and those in the gastro-intestinal tract.1, 3

Protocols since 1996
Since 1996 most radiotherapy departments worldwide have developed protocols for avoiding interruptions in treatments, and for corrections if they do occur. The Royal College of Radiology is very clear about this: ‘There should be a designated person in each department to monitor the frequency of interruptions arising in treatments, determine their cause (table 1) and develop procedures to prevent their occurrence. It is important to stress to all patients and to staff that every effort should be made to avoid interruptions in treatments once started. If this does occur, compensatory treatment is required.’

Overall time and fraction size can be maintained by treating on weekend days (the preferred way, Method 1a) or by using two fractions a day to ‘catch up’ (Method 1b). The latter might incur a small loss of tolerance regarding late reactions, calculated later, when intervals of 6–8 hours and 18 hours are used rather than 24 hours.

How have we been doing in the UK?
In 2005, 63 per cent of the 631 patients in a Royal College of Radiologists (RCR) audit registered by 48 of the 57 UK centres had one or more treatment interruptions, compared to 60 per cent in 2000. However, in 2005 88 per cent of patients with interruptions completed treatment within 1 day of target and 95 per cent within 2 days compared to 69 per cent within 2 days in 2000. So there seems to be a decreasing need for corrections using the second method, requiring individual radiobiological calculations for each such patient. Different countries may have different records in this respect.

A second type of strategy retains overall time and also one fraction per day, but the size of the dose per fraction is increased by a carefully calculated amount. For example, this may be done for the same number of ‘post-gap’ days as gap days (Method 2). However, with this method calculated ‘iso-effect doses’ cannot ever be exactly the same for late reactions as they are for ‘tumour control’, so there is the well-known compromise to be made – a little less tumour control or a little more late complications (Methods 2a and 2b)? Which disadvantage will you choose? It has to be one or the other disadvantage. We shall explain how to estimate their relative size here.1, 3

Methods to compensate for missed days
The methods are discussed more thoroughly in reference 2, all using the same LQ arithmetic, which is no more than introductory algebra, but it depends how rusty you are! Always get your LQ calculation checked by another person!

The tissue-dependent radiobiological ratio alpha/beta
α is the coefficient proportional to the ‘one-hit unrepairable’ radiation damage (e.g. breaking the double

<table>
<thead>
<tr>
<th>TABLE 1. Causes of treatment interruptions</th>
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<tbody>
<tr>
<td>Department-related</td>
</tr>
<tr>
<td>Planned</td>
</tr>
<tr>
<td>Planned</td>
</tr>
<tr>
<td>Public holidays</td>
</tr>
<tr>
<td>Machine service time</td>
</tr>
<tr>
<td>Unwillingness of patient</td>
</tr>
<tr>
<td>Family holiday</td>
</tr>
</tbody>
</table>
strands of DNA) that kills biological cells, and β is the coefficient proportional to damage caused by ‘two or more hits’ (ionisations). If the latter ionisations are delivered at long times or distances apart (as in low doses per fraction or low dose rates), repair can occur in the time between them so the number of cells killed by a given dose of ionising radiation will depend on the time of delivery of dose and this ratio of alpha to beta, designated the α/β ratio. Tumour cells often (but not always) have high α/β ratios, but late-responding normal tissues always have low ratios of α/β. This difference is of vital importance in different tissues, and the choice of dose-per-fraction in radiotherapy will often depend mainly on this α/β ratio.

The basic form of LQ is log cell kill = αd + βd2 = a linear plus the dose-squared term, as described further below and in references 3 and 4.

To compensate for missed dose fractions

Overall time and fraction size can be maintained by treating patients on weekend days (the preferred way, Method 1a), although with unsocial hours and at extra cost, or by using two fractions a day to ‘catch up’ (Method 1b). The latter might incur a small loss of tolerance regarding late reactions when intervals of 6–8 hours are used rather than 24 hours, and there may be logistical scheduling difficulties with larger numbers of patients in some centres.

The object is to maintain prescribed overall time and total biological dose as nearly as possible. I will give you my personal way of using LQ to calculate iso-effective doses. First of all, find out how many days are still to come in the present treatment from the start of the interruption, then calculate relative effectiveness (RE = (1 + d/[α/β])) of the fraction size d being used, using the α/β ratio of the tissue of concern. Then use the seven steps to LQ heaven – meaning you won’t be confused by LQ ever again – to calculate the intended BED (biologically effective dose). The gap in BED to be compensated will then be obvious.

Linear quadratic calculations to keep cell kill constant

Seven steps to LQ heaven

Let E be the number of log(exponential) of cells sterilised by n equal fractions of d Gy each:

\[ E = n (\alpha d + \beta d^2) \]  

(1)

where α is proportional to the one-hit non-repairable cell kill and β is for two or more ionisations (hits) to kill a cell, with repair or recovery occurring if there is time between the hits and if the hits are a long distance apart, as at low doses per fraction.

If you remember this equation, all else is easy.

\[ E = nd (\alpha + \beta d) \]  

(2)

simply takes the d outside the bracket. Now we know that α/β = 3 or 10 Gy for late or early responding tissues, so we want to obtain this ratio in the formula. We could divide either by α or β, but dividing by α is better because it avoids dimensions of beta (in dose squared), which could be awkward.

\[ E/\alpha = nd (1 + \beta d/\alpha) \]  

(3)

Now we want α/β ‘THAT WAY UP’:

\[ E/\alpha = nd (1 + d/(\alpha/\beta)) \]  

(4)

and changing it to the bottom line does that. See? This gives biologically effective dose,4 and NOT biologically equivalent dose!

To change this to the familiar total dose in 2 Gy fractions, just divide any BED by the RE for d = 2 Gy using the α/β ratio of 10 Gy for tumours, but α/β = 3 Gy for normal tissue complications (NTCP). If the relevant normal tissue is spine or brain, use α/β = 2 Gy.

Now we have obtained equation 4 for BED (biologically effective dose) in special ‘biological dose units’, which we can call ‘Gy10’ if α/β was 10 for tumours, or ‘Gy3’ if the normal tissues at risk are late-responding, as they often are. This subscript to give α/β has become usual, but the terms could very well be called Barendsens (8d), to avoid the confusion with physical Gy or the acronym BED mentioned above after equation 4. You see, the α/β is all-important and defines the tissue we are looking at.

This is ‘halfway to LQ heaven’, being the definition of BED as equation 4. You can do a great deal with no further complications, especially to check out the radiation damage you are doing to tumours and, with a different α/β ratio but the same dose, the late damage to normal tissues. (The next three steps allow for proliferation, and this gets much more complicated, requiring three more factors, so I’ll keep it short. Just hang on to equation 4 – only read the next three steps if you’re really interested.)
RE is one of the most useful concepts of LQ algebra.

\[
BED = E / a = n \times d \times (1 + d/\alpha/\beta)
\]

(4)

biologically effective dose

\[
E = (\log_2 2) / Tp
\]

and

\[
\alpha/\beta (\alpha/\beta) /\alpha
\]

(5a)

There are three additional steps, allowing for repopulation in continuing irradiation. You will not need these three steps unless the overall time changes.

The number of cells in a tumour doubles in \( Tp \) days:

\[
Rate = (\log_2 2) / Tp
\]

(5a)

Repopulation starts at time \( Tk \) days, continues to the end of treatment at \( T \) days. So the time available for repopulation is:

\[
T - Tk
\]

(5b)

\[
Total E = nd (a + bd) - (T - Tk) (\log_2 2) / Tp
\]

(6)

but remember that \( BED = E / a \).

So

\[
BED = nd (1 + d) - (T - Tk) 0.693 \alpha/\beta / a Tp
\]

(7)

Don’t forget to finally divide by \( a! \)

That’s the end of our seven steps to LQ heaven. The additional three factors that we have to know, or to guess, so as to estimate the whole BED at the end of a schedule, now include \( a, Tp \) and \( Tk \) as well as \( d \) and \( a/\beta \), which is all we need to compare two schedules.

Remember that to get total dose EQD (in 2 Gy fractions), just divide any \( BED \) by the RE for 2 Gy fractions and the relevant \( a/\beta \) ratio.

How big is this problem for different tumours?

The only reliable way to obtain this information about any sort of tumour is to get data from a controlled clinical trial in which two different overall times were used for two groups of otherwise identical patients, i.e. only the ones treated for longer overall times only by randomisation. This is of course rarely done, so exact data are still rare. However, the rates of tumour repopulation are expected to be related to their measured potential doubling time (\( Tpot \)), which is the period in days required for the number of malignant cells to double, in an untreated tumour that is not experiencing any cell loss.

Many types and locations of human tumours were measured by tritiated thymidine labeling and flow cytometry in the 1980s and 1990s (table 2). Even within one type there will be a wide individual range.

Section 3 (page 14) of reference 2 gives suggestions for priorities of patients by site of tumour, and a list of fast-repopulating tumour sites that should not be given prolonged treatment even for compensation of an interruption. Notable are the very slowly dividing tumours, prostate and brain, which are as slowly proliferating (before any treatment of any kind is given) as late-responding normal tissues, and so invite the use of hypofractionation, as has happened in prostate cancer, followed, increasingly, by breast, and probably bladder, then possibly ovarian cancer. But we are now using this \( Tpot \) data in a speculative way, led still a little cautiously in the case of prostate cancer, which the world of practical radiotherapy is now following. The question marks in the column of \( a/\beta \) values in table 2 are open invitations for useful research. (To find \( a/\beta \) ratios requires good data from different doses-per-fraction.) It is useful if clinicians bear in mind those values of \( a/\beta \) and the somewhat less relevant \( Tpot \)s as possible indicators of where the field might go next.

Examples of corrections for a 5-day interruption (1 week of gap) before half-time interruption.

Let us look at a planned schedule of 30F × 2 Gy in 6 weeks

- Method 1a: maintain overall time by using weekend treatments – the preferred strategy.
- Method 1b: two fractions a day of the usual size, on the remaining days between the gap and the end of treatment, at least 6 hours apart but 8 hours is better. If the gap was longer than 3 days, the dose per fraction should be slightly reduced by calculating for complete repair with bi-exponential \( T^{-1/2} \)s, equally 0.3 and 4

### TABLE 2: The types and locations of the tumours measured*

<table>
<thead>
<tr>
<th>Site of tumour</th>
<th>Number of patients</th>
<th>( Tpot ) (days and range)</th>
<th>Tumour ( a/\beta ) ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Head and neck</td>
<td>712</td>
<td>4.5 [1.8–5.9]</td>
<td>10 Hendry</td>
</tr>
<tr>
<td>Brain and spine</td>
<td>193</td>
<td>34.3 [5.4–63.2]</td>
<td>? Low</td>
</tr>
<tr>
<td>Upper intestinal</td>
<td>183</td>
<td>5.8 [4.3–9.8]</td>
<td>10 Withers</td>
</tr>
<tr>
<td>Colorectal</td>
<td>345</td>
<td>4.0 [3.3–4.5]</td>
<td>? 10</td>
</tr>
<tr>
<td>Breast*</td>
<td>159</td>
<td>14.0 [8.7–17]</td>
<td>4.7 Yarnold</td>
</tr>
<tr>
<td>Ovarian</td>
<td>55</td>
<td>12.5</td>
<td>? &lt;10</td>
</tr>
<tr>
<td>Malignant melanoma</td>
<td>24</td>
<td>7.2</td>
<td>0.6 Bentzen</td>
</tr>
<tr>
<td>Haematological</td>
<td>106</td>
<td>9.6 [2.3–18.1]</td>
<td>?</td>
</tr>
<tr>
<td>Bladder</td>
<td>19</td>
<td>17.1</td>
<td>? &lt;10</td>
</tr>
<tr>
<td>Renal cell</td>
<td>2</td>
<td>11.3</td>
<td>? 2</td>
</tr>
<tr>
<td>Prostate*</td>
<td>7</td>
<td>42 [17–100]</td>
<td>1.5 Miralbel, Hendry</td>
</tr>
</tbody>
</table>

* with extra patients from Haustermans
hours. Two fractions of 2 Gy a day require a total dose reduction of 9 per cent if continued for more than 3 days.

Method 2: maintain overall time with increased dose-per-fraction and one fraction a day. Instead of the usual 15F × 2 Gy = 30 Gy, to tumour and 50 Gy to late NTCP we have only 10 treatment days available to give these doses. Ten tumour doses of 2.81 Gy will solve the tumour problem, giving 36 Gy to as required, to the full BED. But these same doses will deliver more than the planned 50 Gy to late NTCP, in fact 54.4 Gy, making the late complications BED 104.4 Gy, now 4 per cent higher than our prescribed 100 Gy. This could lead to 8–12 per cent more late complications than the usual proportion. Is that an acceptable risk? If not we have to come down by ~2 per cent on the planned total dose to tumour, which would be a 4 per cent reduction in tumour control probability. Such compromises are usual if interruptions occur.

So it is important not to allow interruptions.

REFERENCES


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Estimating muscle volume using ultrasound

Benjamin W. Infantolino¹,² and John H. Challis² used ultrasound, rather than conventional imaging, to measure muscle volume in vivo.

Abstract

An important descriptor of muscle architecture is muscle volume, particularly because the power a muscle can produce is directly proportional to its volume. The tracking of muscle volume in vivo can be useful for example for examining how muscle size changes during childhood, during disease processes and for the tracking of muscle changes due to rehabilitation exercises and training for sports. Muscle volume is typically estimated using an imaging method, such as magnetic resonance imaging (MRI) or computed tomography (CT), to obtain views of the muscle cross-sections. From these muscle cross-sections, the area of each image is measured and from series of these cross-sections and the distances between them the muscle volume can be estimated.

The purpose of these studies was to demonstrate that muscle volume can be estimated in vivo by using ultrasound, a cheaper, more portable and less contraindicated imaging method compared with MRI or CT. To evaluate ultrasound as a method to determine muscle volume, vastus lateralis and first dorsal interosseous muscles were imaged in cadavers. Then the muscles were dissected and their volumes measured directly; the direct measures of volume and their estimated volumes were compared.

The results demonstrated that ultrasound can be used to accurately estimate muscle volumes in vivo. The muscle volumes used ranged from some of the smallest to the largest found in the human body, showing the general utility of ultrasound for measuring muscle volume in vivo.

Introduction

The geometrical arrangement of muscle (called muscle architecture) is important in dictating the function of a muscle. Measurement of muscle architecture in vivo is important for tracking disease processes, the impact of rehabilitation protocols, muscle changes with ageing and for the construction of subject-specific muscle models. One aspect of muscle architecture, muscle volume, can be used to estimate the maximal power a muscle can produce.

Muscle power production is a crucial indicator of performance; for example, in the elderly the ability to produce power is strongly related to the ability to perform activities of daily living.¹ The measurement of muscle volume in vivo allows clinicians to track the

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Benjamin W. Infantolino¹,² and John H. Challis² used ultrasound, rather than conventional imaging, to measure muscle volume in vivo.

AFFILIATIONS

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MUSCLE VOLUME FEATURE
progress of a muscle training programme or a disease, and allows researchers to gain better insight into the functions of muscles.

Muscle volume has been estimated using magnetic resonance imaging (MRI), computed tomography (CT), or ultrasound. Irrespective of the imaging modality, all muscle volume estimations are performed using the Cavalieri principle. Previous studies have used one imaging modality to assess the accuracy of the other imaging modality. The limitation to this method of accuracy assessment is that the error associated with one imaging method (e.g. muscle identification) is the same for the other imaging modality, so under this paradigm no gold standard exists. Scott et al. used MRI to estimate the volume of 18 muscles in the lower leg of one cadaver and compared the estimated volumes with the muscle volumes measured using water displacement. The limitations of their study were that only one leg was examined, and that the muscles examined were some of the larger ones in the human body.

Drawbacks exist for both MRI and CT for the estimation of muscle volume in vivo. MRI is contraindicated for patients or subjects with metal implants and for individuals with claustrophobia. CT is a radiation-based imaging modality, so the repeated muscle volume measurements that would be required for tracking muscle volume changes due, for example, to ageing are not feasible. Ultrasound does not have the contraindications of MRI nor the radiation concerns of CT. In addition, ultrasound equipment is much cheaper and portable than carrying out MRI and CT. The purpose of the following study was to examine the accuracy of ultrasound in estimating muscle volume for the range of muscle sizes found in the human body.

Methods

General methods
To estimate muscle volume using ultrasound the proximal and distal ends of the muscle are located using ultrasound. This length of the muscle is divided into equally spaced (1 to 2 cm) intervals. If the muscle is too wide to be viewed with one ultrasound scan the muscle is divided using thin (22 gauge) wires. The wires show up on the ultrasound image, ensuring no part of the muscle would be missed or double counted, as shown in figure 1. Ultrasound images of muscle cross-sections (see figure 2) are saved to a personal computer for further processing. Once the entire muscle is imaged, the cross-sectional area of the muscle in question in each image is measured using the freeware program Scion Image (now ImageJ, http://rsweb.nih.gov/ij/). Successive cross-sectional areas (CSA) and the distance (h) between them allows computation of total muscle volume (V) estimated using the Cavalieri principle:

\[
V = \frac{1}{3} \sum h_i \left( CSA_i^2 + 2 \cdot CSA_i \cdot CSA_{i+1} + CSA_{i+1}^2 \right)
\]

(MUSCLE VOLUME FEATURE)

(a) FIGURE 1. [TOP] Wires showing how the muscle is divided
(b) FIGURE 2. [TOP RIGHT] Ultrasound images of muscle cross-sections
(c) FIGURE 3. [LEFT] The vastus lateralis is a large muscle in the superficial lateral thigh
(d) FIGURE 4. [MIDDLE RIGHT] The first dorsal interosseous muscle is a small muscle in the first web-space of the hand
(e) FIGURE 5. [BOTTOM RIGHT] The system of wires used to break up the vastus lateralis

Muscles analysed
Two different muscles were analysed: the vastus lateralis and the first dorsal interosseous. The vastus lateralis is a large muscle in the superficial lateral thigh, figure 3, and represents one of the larger muscles in the human body. The first dorsal interosseous muscle is a small muscle in the first web-space of the hand, figure 4, and represents one of the smaller muscles in the human body. The vastus lateralis muscles of four cadavers were imaged but in one case the vastus lateralis was fused to the next muscle deeper giving a total of seven muscles analysed, and the first dorsal interosseous muscles of 11 cadavers were imaged giving a total of 22 muscles analysed. All cadavers were embalmed and all cadaveric research was performed following institutional-approved ethical, safety and biohazard standards.

Muscle scanning
Both muscles, the vastus lateralis and the first dorsal interosseous, were scanned using a 7.5 MHz linear ultrasound probe (SSD-1000, Aloka, Japan) in B-mode. To enhance muscle image quality a stand-off pad (2 cm thick and 9 cm in diameter) and a small amount of ultrasound gel were used. Both the stand-off pad and ultrasound gel aid in the transmission of sound waves between the probe and the body. The skin was marked with a wax pencil in 2 cm (vastus lateralis) or 1 cm (first dorsal interosseous) increments from the distal to the proximal end of the muscle. The vastus lateralis is wider than the ultrasound probe and so the system of wires was used to break up the vastus lateralis (figure 3) whilst the first dorsal interosseous was imaged in one ultrasound image.

Direct muscle volume measurement
Once the muscles were imaged, they were removed from the cadavers using blunt dissection. Immediately upon removal the mass of each muscle was determined using an electronic balance. Muscles were then placed in a self-sealing polyethylene bag and evacuated of air to prevent loss of fluid. Muscle volume was then determined directly. For the vastus lateralis muscle underwater weighing was used. The first dorsal interosseous muscle was too small for underwater weighing to be accurate so the water displacement method was used instead. In both cases the muscles remained in the bag to prevent fluid transmission and the mass of each muscle was measured after volume determination to confirm that no fluid was lost or absorbed.

Operator reliability
For the vastus lateralis intra-operator reliability was assessed. The volume of a muscle was estimated from one set of muscle images by three operators. Inter- and intra-operator reliability was assessed for the first dorsal interosseous. One operator estimated muscle volume from the same image set twice for all muscles and two operators estimated muscle volume using the same image set for all muscles.
Finally, since probe orientation with respect to the normal can cause a change in the area of muscle cross-section being imaged, one first dorsal interosseous muscle was imaged with varying probe orientations. The estimated muscle volumes were compared for the probe oriented perpendicular to the muscle surface and at 5 degrees off of the normal angle. Five degrees was chosen because anything greater than this is easily visually identified and would be corrected by the operator before the image is recorded.

Statistics
For the comparison between estimated and direct muscle volumes the graphical method of Bland and Altman was followed. In this method, the differences between measures (directly measured and estimated muscle volume) are plotted against the mean of the two measures. The straight line fit to this data indicates whether there was relative bias in the data (constant offset), and the line’s gradient indicates whether there was proportional bias in the data. To compare inter- or intra-operator errors, intra-class correlations (ICC; 2.1) were computed. To assess whether probe orientation had an influence on estimated muscle volumes a repeat measures of variance was computed.

Results
The Bland–Altman plots of two measures of muscle volume for both the vastus lateralis and first dorsal interosseous muscles indicated that the measures fell within a 95 per cent confidence interval of agreement between the ultrasound measures and the direct volume measures (figures 6 and 7). These data also did not have a relative bias (p > 0.05) or a proportional bias (p > 0.05).

For the vastus lateralis the intra-class correlation was high (ICC > 0.8) between three measurers. For the first dorsal interosseous the intra-class correlation was high (ICC > 0.8) between two measurers, while for this muscle the intra-class correlation was high (ICC > 0.8) for repeat measures made by the same measurer.

Probe orientation did not have a significant effect on estimates of the first dorsal interosseous muscle volumes (p > 0.05).

The scanning of muscle to determine its architecture has a number of important implications.

Discussion
The results of these studies indicate that the volume of human muscles can be estimated both accurately and reliably using ultrasound. Inter- and intra-operator reliability was high, indicating that the volume estimates are repeatable for the same operator and different operators. Probe orientation was also found not to have an effect on muscle volume estimation. It is possible that probe angles relative to the muscle greater than 5 degrees could produce significant differences in muscle volume estimates but this deviation would be easily noticed by eye and could be corrected.

The range of muscle sizes investigated in the studies spans nearly the entire range of muscle sizes in the human body, indicating that this technique is accurate for all muscles in the human body. One
Applications and benefits
Models of the musculoskeletal system are becoming increasingly popular for the analysis of human movement, in particular for making surgical decisions.14 The in vivo determination of particular muscle architectural parameters using ultrasound therefore has implications for producing subject-specific muscle models within these models of the musculoskeletal system.

The determination of muscle volume is important for determining a component of muscle function. Experience indicates that imaging muscles of live subjects produces better images than those obtained from cadavers, which would lead to an even greater accuracy of this method than the results that we determined in our studies.

Conclusion
Ultrasound is an ideal imaging modality for the in vivo determination of muscle volume. Ultrasound does not have the contraindications of imaging by MRI (metal implants and claustrophobia, for example) or the radiation concerns of CT. Additionally, ultrasound is cheaper and more portable than MRI and CT, making it an ideal imaging modality for a range of clinical applications, for example tracking muscle hypertrophy or atrophy.

References

ICMP2013: booking open for a visit to Brighton

Peter Jarritt introduces the next International Congress on Medical Physics taking place in Brighton and encourages you to register now!

The majestic Royal Pavilion, Brighton

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The International Congress on Medical Physics (ICMP), taking place in Brighton in September 2013, will be a uniquely important event in the medical physics and clinical engineering calendar. It will bring together IPEM’s prestigious annual scientific meeting with the premier international medical physics conference of the year in one ambitious event. ICMP2013 also incorporates the 7th European Congress of Medical Physics; it will host the first ever retrospective exhibition on eminent contributors to the field of physics; and it will be the focus of the 50th anniversary celebrations of the International Organization for Medical Physics (IOMP).

IOMP began in 1963 as a small coalition of just four affiliated national member organisations, but with some very big ambitions. It aimed to do no less than to organise international cooperation in medical physics; to promote communication between the various branches of medical physics and the allied subjects; and to contribute to the advancement of medical physics in all its aspects. Now known globally as a scientific, educational and professional organisation, and with more than 18,000 members from 82 national bodies and six regional organisations, IOMP has plenty to celebrate. Its first conference, in 1965, 2 years after its launch, took place in Harrogate, so it is fitting that it should return to the UK to mark its 50th anniversary in Brighton.

But ICMP2013 is not only about recognising history and achievements to date. The theme of the conference is ‘New Horizons – Global and Scientific’, and a carefully chosen mix of plenary sessions from world-leading scientists, and proffered papers from the cutting edge of research and development, will provide delegates with an abundance of information, stimulation and food for thought.

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thought. On the Sunday, prior to the official opening ceremony, there will be a whole day of educational sessions, and the Hospital Physicists’ Association, celebrating its own 75th anniversary, is sponsoring a public lecture by Peter Marsden from University College London Hospital. IPEM’s hard-working outreach volunteers will be there to ensure that school children can experience some ‘hands-on’ science – and at the global end of the scale, there will also be a stream on the same day about medical physics in Africa.

Throughout the next three full days of the conference, delegates will have the choice of attending several busy themed streams, including novel medical devices; medical imaging and diagnostic techniques; cancer treatment methods and technologies; radiation protection and dose reduction methods; and rehabilitation and assistive living technologies.

Between these sessions will be the chance to come together as a full conference for some unmissable plenary sessions. One of these will feature Molly Stevens, Professor of Biomedical Materials and Regenerative Medicine at Imperial College, London, who will deliver the prestigious Woolmer Lecture. Professor Stevens was recently recognised by the TR100, a compilation of the top innovators under the age of 35 who are transforming technology with their work.

As a bonus for IPEM members, the Institute’s Annual General Meeting will be held during the conference, giving members a chance to hear about, and vote on, some of the major changes proposed for the professional body. Members will also have a chance to meet the incoming President of IPEM, Professor Steve Keevil, as he takes office. With a full social programme involving both fish and chips and a visit to the Brighton sewers, and a major commercial exhibition of industry partners showcasing the latest developments in the field, this will be a conference with something for everyone.

Abstract submission is now open, bursaries are on offer to help those struggling with funds to attend, and more speakers are being added every week. To keep up with the conference news, visit the dedicated website at www.icmp2013.org, find it via the IPEM site www.ipem.ac.uk, or follow the conference on Twitter using #ICMP2013. Delegate booking opened in May, and IPEM members can book directly using the new online system.

Standing on a firm, 50-year foundation and looking forward to new and exciting horizons, this event is going to be the IPEM highlight of 2013 – don’t miss it!
Medical equipment in Africa

Shauna Mullally reports on an innovative new programme to improve the maintenance and management of medical equipment in developing countries

Hospitals in low- and middle-income countries frequently report the poor state of medical equipment as being a key challenge they face in delivering essential services. WHO statistics are alarming. It is estimated that between 50 and 80 per cent of medical equipment is out of service in these regions. One of the biggest reasons for this is the lack of trained maintenance personnel. The Tropical Health and Education Trust, a specialist global health organisation that educates, trains and supports health workers through institutional partnerships, has introduced a new programme to support training in this crucial area.

With funding provided by the Department for International Development, qualified biomedical engineers from the UK are being engaged as global health volunteers to share their skills and support their colleagues in Ghana, South Sudan, Ethiopia, Uganda and Zambia.

For example, the partnership between University College London, University College London Hospital, Royal Berkshire Hospital and Korle Bu Teaching Hospital in Ghana is preparing for the arrival of Ghana’s first linear accelerator in a public hospital. There are currently only two treatment units publicly available to cover Ghana’s population of 26 million. In the UK this population would be served by over 100 units. There are currently no personnel trained to use or maintain linacs in any public hospital in Ghana.

The projects were announced by Lord Nigel Crisp last September and we look forward to tracking their progress here in Scope.

Medical equipment training in Zambia

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The European Congress for Thermology forms a key international meeting in the field of medical thermography. It is held every 3 years and this year it was hosted by the Faculty of Engineering University of Porto (FEUP), Portugal, with Professor Joaquim Gabriel and Dr Ricardo Vardasca the main meeting organisers. On day 1, of the 4-day meeting, there was a pre-congress certificated training course in medical thermography followed by the European Association of Thermology (EAT) General Assembly meeting. Days 2 and 3 accommodated the main scientific sessions, and day 4 focussed on a social event comprising a day-long boat trip along the dramatic landscape of the River Douro. The city of Porto is shown in figure 1.

A total of 70 delegates were in attendance; most were European but there were also researchers from the US, Japan and South America (figure 2). There were four keynote presentations and approximately 60 further oral and poster presentations. The abstracts for the presentations at the meeting have been published in the journal Thermology International (2012; 22(3)) and the full paper, in digital format, as the Appendix I.

The EAT Certified Thermography Course is a unique training course in medical thermography and covers topics including heat exchange and IR radiation, thermal physiology, equipment operation, medical reasons for temperature changes, physiological provocation tests, image analysis and reporting, examples of applications in medical thermography and educational resources in medical imaging. A practical session on thermal imaging methods was also included (figure 3). These training courses tend to be held infrequently but further information can be obtained from Dr Vardasca and Professor Francis Ring (University of Glamorgan) on request.

The scientific sessions held from Day 2 opened with the first keynote presentation given by Professor Ring entitled ‘The history of thermology and thermography – the pioneers and milestones’ (figure 4). This was a fascinating overview with historical perspectives from the sixteenth century to date. Thermal imaging has come a long way since William Herschel identified dark heat in 1800, through Carl Wunderlich’s thesis on
There were then two presentations on core relative temperature changes over time. Patient as a control to track their own body sites, and the utility of using each ranges needing to be specified for different core temperature, normal temperature important questions about the definition of Futurum, Sweden). The speaker raised, Jönköping & clinical spot temperature thermometers assessing core body temperature using uncertainty in measurements when opening oral presentation discussed the programme was thermal physiology. The first main topic of the scientific lecture Thermal physiology The first main topic of the scientific lecture programme was thermal physiology. The opening oral presentation discussed the uncertainty in measurements when assessing core body temperature using clinical spot temperature thermometers (Mártha Sund-Levander, Jönköping & Futurum, Sweden). The speaker raised important questions about the definition of core temperature, normal temperature ranges needing to be specified for different body sites, and the utility of using each patient as a control to track their own relative temperature changes over time. There were then two presentations on core temperature which explored the use of weighted formulae for estimating core temperature (Emilia Quelhas Costa, University of Porto, Portugal, and David Pascoe, Auburn University, AL, USA). Joana Guedes (University of Porto, Portugal) then described the use of a state-of-the-art climatic chamber for the assessment of psychosocial responses to varying temperature and humidity levels. John Allen (Newcastle upon Tyne) presented work on the standardised testing of skin temperature and microvascular blood flow changes (using photoplethysmography) with controlled induced gasp manoeuvre to produce repeatable vasoconstrictor waves, quantifying the expected normal ranges for the magnitudes and relative delays between physiological signals.

These are important considerations to help reduce uncertainty in measurement

The second and main topic for the scientific lecture programme was applications of clinical thermography with a wide range of medical conditions covered, including: staging patients with complex regional pain syndrome (CRPS) (Timothy Conwell, Colorado Infrared Imaging Center, Denver, CO, USA, and Luigi Laino, Roma Studio Dermatologico Venereologico, Rome, Italy), hand–arm vibration syndrome assessment (Ricardo Vardasca, University of Porto, Portugal), whole body vibration and skin temperature of the lower extremities in healthy subjects (Adérito Seixas, University of Porto, Portugal), infantile hemangioma treatment by propanolol (Francis Ring), abdominal skin circulation pre- and post-plastic surgery (Cristina Vicari Nogueria, Barcelona Autonoma University, Spain), detection of subclinical varicocele in the scrotum (Arcangelo Merla, G. d’Annunzio University, Italy), highly focalised thermotherapy in the treatment of solid tumours (Ana Portela, University of Porto, Portugal), application of cold provocation for breast cancer screening (Piotr Przynusiała, Termowizja S.A., Lodz, Poland), fever screening (António Cardoso, CATIM, Portugal), Graves’ orbitopathy (John Allen), effect of yoga and swimming on the body temperature of pregnant women (Manuel Sillero-Quintana, Universidad Politécnica de Madrid, Spain), mother and child in synchrony: thermal facial imprints of autonomic contagion (Arcangelo Merla), assessing the effectiveness in reducing post-operative swelling with facial cooling in a pilot study of healthy controls (Kevin Howell, Royal Free and University College Medical School, London), detecting hypothermia (H. Usuki, University of Kagawa, Japan), bone temperature evolution (António Silva, University of Porto, Portugal), application of cold provocation for breast cancer screening (Ana Portela, University of Porto, Portugal), transfemoral amputees stump and socket (Emilia Mendes, University of Strathclyde) and a literature review of the temperature of the human knee (Kurt Ammer, Österreichische Gesellschaft für Thermologie, Austria).

A keynote clinically-focussed talk was then given by Professor James Mercer (University of Tromso, Norway) entitled ‘Thermography in plastic surgery’. He described the use of thermal imaging in pre-, intra- and post-surgical monitoring of skin flap graft perfusion. Pre-surgical thermography, with local skin cooling from a fan device, was shown to help the clinician locate subcutaneous graft ‘perforator’ vessels for graft transfer. The key advantages of using thermography over Doppler ultrasound were given to add extra weight for the technique in theatre. Fan cooling was
FIGURES 5A, B AND C. Example thermal images of (a) patient with diagnosed complex regional pain syndrome in the lower limbs, (b) active stage thyroid eye disease and (c) skin fat tumours

used to enhance the thermal contrast to improve technique sensitivity. Post-operative monitoring of a graft flap area with thermography could also give early feedback on the complications that can require urgent reconstructive surgery. A key physiological feature to look for as an indication of likely graft success was the presence of a skin tissue hyperaemia at between 2 and 6 days post-surgery.

**Thermal imaging methods**

The third topic of the scientific programme was thermal imaging methods, image analysis, calibration and quality assurance, commencing with a lecture on the assessment of calibration and evaluation procedures for thermal imaging metrology at the National Physical Laboratory in the UK (Rob Simpson, NPL, Teddington). A range of methodological papers then followed including integrating medical thermography into RIS using the DICOM standard (Tomé Vardasca, University of Porto, Portugal), the histographic method as a tool for thermal image processing (Imre Benkő, Budapest University, Hungary) and reliability and reproducibility of skin temperature of overweight subjects using infrared thermography software (Ismael Fernández-Cuevas, University Politècnica de Madrid, Spain). I then presented a paper describing his experiences over a decade in the Newcastle imaging facility. Example thermograms collected in the Newcastle imaging facility are shown in figure 5.

The final topic was the application of thermal imaging to equine medicine. Simone Westermann (University of Vienna, Austria) opened the session with the keynote lecture ‘Thermography in equine medicine and the different environmental factors on the thermographically determined temperature’. Similar to humans, horses also demonstrate thermal symmetry in health. Horses also have an emissivity value for their surface tissue close to 1, similar to human skin. Dr Westermann summarised the main standard thermography views used in horse assessments, with standard distances, choice of camera angle, time of day for measurements and the practical considerations for keeping the horse still during imaging. A suggested protocol was given, choosing a thermal ambient of close to 20°C, avoiding measurements in direct and strong sunlight, choosing an environment with minimal local air flow, and not to take measurements when the horse’s coat is wet. Artefacts can result from dirt, scar tissue and with excess hair length. A key application for thermal imaging is to detect tissue inflammation from warm joints. Dr Westermann noted that a thermal asymmetry of >1°C may indicate pathology. Ram Purohit (University of Auburn, AL, USA) then gave two talks: ‘The effect of high regional nerve block on the thermographic patterns in the limbs of horses’ and ‘The legality associated with the use of infrared thermal imaging in veterinary medicine’. Maria Soroko (Wrocław University, Poland) closed the session with a talk on the use of thermography to evaluate musculoskeletal responses in the backs of young racehorses in advanced levels of training.

**Events involving alcohol**

In setting the scene for the main social events involving alcohol, the fourth and final keynote lecture was presented by Olga Grant (National University of Ireland Maynooth, County Kildare, Ireland) entitled ‘Thermography in viticulture’. She provided a fascinating overview of wine production and in particular hydration of the vine and how this can be remotely monitored to help maximise yield. It is important to detect plant stress early, and using remote optical monitoring can help facilitate precision irrigation, especially in areas of reduced water supply. Dr Grant described the practical options available to assess vast land vine areas, including the thermal imaging of vine rows remotely from a light aircraft. She also discussed current work in genetic improvement of the vine to optimise growth and subsequent yield.

The congress dinner was held at Taylor’s Port and Wine Cellar in Porto. Delegates were invited to taste one of their fine port drinks whilst warmly receiving musical and visual entertainment from a violinist – Ianina Khmelik (Russia) – playing a contemporary piece, artistically arranged to have live thermal images of her projected whilst she played. Several prizes were awarded at the dinner: best overall oral presentation for ‘Mother and child in synchrony: thermal facial imprints of autonomic contagion’ (Arcangelo Merla, University Chieti-Pescara, Italy), best student oral presentation (the Francis Ring prize) for ‘The highly focalised thermotherapy in the treatment of solid tumours: temperature monitoring using thermography’ (Ana Portela, University of Porto, Portugal) and best poster presentation (the Kurt Ammer Prize) for ‘A method for whole-body human skin temperature mapping’ (Damien Fournet, University of Loughborough).

Overall, the congress was well organised and well attended. I found attending the meeting a fabulous experience and I thank IPEM for their generous contribution to my travel costs from their IPEM Travel Bursary Award to allow me to make the trip. It was also a great pleasure to visit the city of Porto and to experience the culture and great warmth of the people there. It was certainly worth going. I have also made new professional contacts in medical thermography. ■
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PET neuroimaging research in the US: A 3-week research visit

THERESE SÖDERLUND Nuclear Medicine, University College London Hospital

In my job at the University College London Hospital I have been heavily involved in the department’s neuroimaging services and I have developed a keen interest within this field. The department currently performs a range of brain imaging procedures, including 18F-FDG PET and 99mTc-HMPAO-SPECT for epilepsy, 18F-FDG and 18F-florbetapir PET for dementia and 11C-FP-CIT SPECT for Parkinsonian syndromes. A number of tracers are also used for oncological brain applications (e.g. 18F-Choline and 123I-FP-CIT). In my role as a clinical scientist I perform routine, development and research work within this field.

In 2012 I was fortunate to receive an IPEM/AAPM travel award. This enabled me to travel to the United States for 3 weeks in October 2012, visiting high-profile centres performing PET neuroimaging research.

A hallmark of Alzheimer’s disease is the formation of amyloid plaques in the brain.

Imaging in Alzheimer’s disease

Alzheimer’s disease is currently affecting about 5.4 million Americans, with about 45 per cent of the population over the age of 85 being affected. With the baby boom generation now reaching the age of 60 and the expected increase in life expectancy, it is projected that between 11 and 16 million Americans over the age of 65 will have the disease in 2050. The burden this will place on the healthcare system will be enormous. The projected numbers are, however, given with the condition ‘baring the development of medical breakthroughs to prevent, slow or stop the disease’ and research is currently ongoing worldwide to tackle this.

A hallmark of Alzheimer’s disease is the formation of amyloid plaques in the brain. According to the amyloid cascade hypothesis the formation of amyloid plaques is considered a key pathogenic event of the disease, with accumulation in the brain starting years prior to clinical symptoms. β-amyloid (Aβ) is the main constituent of amyloid plaques, previously only visible microscopically in the brain during post mortem examination. PET tracers have, however, recently been developed enabling in vivo imaging of Aβ and the potential for early detection of Alzheimer’s disease.

Pittsburgh

I spent a week in the PET imaging research center at the University of Pittsburgh Medical Center under the supervision of Professor Julie Price. Current research topics for this group include imaging in Alzheimer’s disease, neuroreceptor imaging, evaluation of novel oncology tracers and evaluation of efficacy of drug therapy in tuberculosis patients. The centre became known worldwide for the development of the 11C Pittsburgh Compound-B (PiB) tracer, which can be used for imaging in Alzheimer’s disease. The tracer binds to fibrillar Aβ deposits in the brain at PET ligand concentrations. The proof of concept study was published in 2004, showing group differences in tracer uptake between healthy controls and subjects with Alzheimer’s disease. A number of studies have since been published by the Pittsburgh group and others, further validating the tracer and exploring its potential clinical usage areas.

In Pittsburgh I mainly concentrated on learning about the validation work performed when developing the PiB tracer, in particular the work carried out to find valid methods for Aβ deposition quantification. To investigate the characteristics of PiB amyloid binding, the group initially used a fully quantitative approach. Cognitively healthy controls, subjects with mild cognitive impairment and subjects with Alzheimer’s disease were intravenously injected with 11C-PiB, followed by dynamic PET data acquisition and arterial plasma sampling over 90 minutes. The plasma samples were used to measure the tracer input to tissue, while manual regions of interest were drawn over grey and white matter areas of the brain to assess the tissue response to this input. Kinetic components were found using spectral analysis, supporting the use of a two-tissue, four parameters compartmental model. This type of compartmental model was also shown to best describe the acquired data (figure 1). Distribution volume ratios were calculated from model parameters, giving a quantitative measure of the tracer binding in various brain areas (figure 2).
The group then proceeded to look at simplified quantitative methods as described by Lopresti et al. This is essential for routine use, both in terms of easier implementation and improved patient compliance. A variety of approaches were evaluated, including looking at the need for arterial blood sampling, the possibility of using a shortened scan time and the use of semi-quantitative measures. Each method’s performance was evaluated in terms of bias, test-retest variability, effect size and inter-subject variability. Encouragingly, the use of a late single-scan time and semi-quantitative analysis of tracer binding in the form of a standardised uptake value ratio proved to give the largest group differences with good inter-subject and test-retest variability. This was however shown to come at the cost of introducing a strong positive bias in the data. Overall, it was highlighted that each quantitative or semi-quantitative method has its advantages and disadvantages, with the method of choice being highly dependent on the clinical application.

The group is involved in a number of trials looking at the clinical utility of amyloid PET tracers. Some of the current projects that I was able to gain insight into were:

- Mild cognitive impairment. Subjects with mild cognitive impairment have memory deficits that do not significantly impact their daily function. The conversion rate to Alzheimer’s disease is about 10–20 per cent each year.
- Familial Alzheimer’s disease. This is an inherited form of Alzheimer’s disease in which subjects are affected early in life (<65 years of age).
- Down’s syndrome. Subjects with Down’s syndrome have an increased risk of developing Alzheimer’s disease compared with the general population. The reason for this is not completely known, but it has been shown that the amyloid precursor protein, thought to be a driving factor of amyloid plaque deposition in the brain in Alzheimer’s disease, is produced from a gene on chromosome 21, the trisomy of which leads to Down’s syndrome.
- Cognitively normal healthy controls. It has been shown that cognitively healthy elderly people can have amyloid plaque depositions in the brain without showing any clinical signs of Alzheimer’s disease. The clinical implication of this is not yet understood.

- Looking at post-mortem amyloid load and comparing histopathological results with fibrillar Aβ burden seen on 11C-PiB images of the same subjects.
- Evaluation of 18F amyloid tracers. A number of 18F-based tracers are currently being evaluated with their performance compared to the 11C-PiB compound. One clear advantage of 18F tracers would be that an on-site cyclotron is not needed, enabling more widespread usage.

Berkeley

I also spent a week at the Jagust Laboratory in Berkeley, California, which is a joint research programme involving the UC Berkeley Helen Wills Neuroscience Institute, the UC Berkeley School of Public Health and the Lawrence Berkeley National Laboratory (figure 3). The lab is led by Professor William Jagust and specialises in the study of brain ageing and dementia using PET and MR imaging, neuropsychology and cognitive neuroscience. The data analysis methods used tend to be automated voxel-based methods such as Statistical Parametric Mapping. Within the lab there are a number of ongoing projects investigating the usage of the 11C-PiB compound and during my visit I was able to learn more about some of these research topics.

The lab runs the Berkeley Aging Cohort Study, enrolling cognitively normal elderly volunteers from the local area. The study of the cognitive healthy elderly is important as it has been found that a large proportion of these subjects have Aβ brain depositions although not showing any clinical signs of Alzheimer’s disease. To address this, the Berkeley Aging Cohort Study is set up as a longitudinal study of healthy elderly volunteers undergoing cognitive tests and imaging in the form of 18F-PET/CT, 18F-FDG PET/CT and structural and functional MRI. The group is hoping to answer questions such as why some cognitively normal subjects have high levels of Aβ deposition and whether these cognitively normal subjects are on a trajectory towards developing Alzheimer’s disease. A recently published paper from the study compared
lifetime cognitive and physical engagement with \(^{11}C\)-PiB binding. It was shown that subjects with greater early- and mid-life cognitive activity had lower levels of fibrillar \(^{11}C\)-PiB brain depositions. An association between physical exercise and \(^{11}C\)-PiB binding, however, was not found.

A second large-scale study that the Jagust lab is involved in is the Alzheimer’s Disease Neuroimaging Initiative (ADNI).\(^{9}\) This is a longitudinal multi-centre study looking at normal cognitive ageing, mild cognitive impairment and Alzheimer’s disease. The goal is to evaluate imaging biomarkers (MRI and PET) and other biomarkers (e.g. coming from CSF and blood tests), aiming to identify the best method of analysis for tracking Alzheimer’s disease over time. The hope is also that this will aid clinical drug trials that use these biomarkers as outcome measures. As the PET core centre the Jagust lab is responsible for ensuring standardisation of PET data acquired across the 50 sites participating in the study. This includes the major task of performing quality control of all acquired PET data, e.g. assessing each scan’s sinogram for artefacts and all reconstructed images for motion.

**Imaging in Parkinsonism**  
Parkinsonism is an umbrella term describing a number of conditions sharing clinical symptoms such as tremor, muscle stiffness and slowness of movement. Of these, idiopathic Parkinson’s disease and atypical Parkinsonian syndromes such as multiple system atrophy, corticobasal degeneration, Lewy Body dementia and progressive supranuclear palsy have the common characteristic of causing a dopamine deficiency in the basal ganglia. Although assessment of clinical symptoms is usually sufficient for a diagnosis, imaging can be helpful in difficult cases. Commonly, PET and SPECT tracers targeting different parts of the dopaminergic pathway are used to differentiate between, for example, essential tremor and Parkinson’s disease, and Lewy Body dementia and Alzheimer’s disease.\(^{10}\)

**New York**  
I spent a further week at the Functional Brain Imaging Laboratory at the Feinstein Institute for Medical Research on Long Island, New York, under the supervision of Professor David Eidelberg. This centre performs work in developing novel PET and MR imaging techniques to characterise neural circuits in neurodegenerative disorders. Current research areas include nervous system diseases such as Parkinson’s disease, Huntington’s disease and the dementias. In contrast to many centres using tracers directly targeting the dopaminergic pathway, the lab at the Feinstein Institute is developing the usage of \(^{18}F\)-FDG PET for imaging in Parkinsonism. Being a glucose analogue, FDG uptake reflects the brain’s metabolism and as such synaptic integrity. During my week at the Feinstein Institute I concentrated on learning about the principal component analysis method used by the lab for data analysis and its potential clinical applications.

The lab uses the hypothesis that patients with Parkinsonism show a changed metabolic pattern of \(^{18}F\)-FDG brain uptake compared to healthy subjects. Data analysis is performed by using a type of principal component analysis called Scaled Subprofile Modelling.\(^{11}\) This is a completely data-driven analysis method in which the dataset is first transformed to only look at variables that capture most of the variance. The principal components of the dataset are then found, which in essence are linear functions looking at the inter-correlation between dataset regions (voxels or regions of interest). The group is therefore taking a functional integration approach to explain brain function, in which function is seen as a product of interacting brain areas within networks. This can be contrasted to the more traditional approach of functional segregation, where brain function is explained as being localised to specific areas within the brain.

By using test populations of healthy controls and subjects with known Parkinsonism the group has been able to identify and validate specific metabolic patterns in Parkinson’s disease and atypical Parkinsonian syndromes.\(^{12}\) These patterns can then be used to score single subject scans, with z-scores calculated to describe the magnitude of the expression of a particular network that the subject is showing. Current...
projects that I was able to learn more about during my week at the lab include:

- Validation of the analysis method for clinical use. For this purpose the group at the Feinstein Institute is collaborating with groups in Germany, Holland and China.
- Assessment of pattern expression in patients with REM sleep disorders. As a large portion of these subjects go on to develop Parkinson’s disease the metabolic pattern observed has the potential to be used as a biomarker for patients with REM sleep disorders, potentially being used to calculate the likelihood of a patient developing Parkinson’s disease.
- Utility of metabolic patterns in treatment response studies.

Conclusion
The travel award has significantly expanded my knowledge of current PET neuroimaging research topics, in particular in Alzheimer’s disease and Parkinsonism. From a clinical scientist’s perspective it has been particularly interesting to learn more about the different data analysis approaches taken by the research groups I visited. The group in New York is, for example, using a completely data-driven method, with the data analysed using a type of principal component analysis, followed by an explanation of the outcome using known clinical attributes of test populations. In Pittsburgh the approach, on the other hand, is to use hypothesis-driven data analysis methods, e.g. with regions of interest drawn over areas known to be affected by Alzheimer’s disease followed by quantification of tracer uptake using compartmental modelling. The different data analysis methods dictate whether the centres use segregated or integrated approaches to explain brain function, with the Aβ uptake assessments performed in Pittsburgh and Berkeley in general using a segregated approach and the principal component analysis used at the Feinstein Institute assuming networks within the brain and hence an integrated approach. During my visit I was also able to learn more about different PET systems available on the market, including interesting discussions with the team in Pittsburgh about the PET/MR scanner that has recently been installed at both the University of Pittsburgh Medical Center and also the University College London Hospital.

In addition to the professional learning outcomes, the travel award has enabled me to meet many interesting people and to visit new places. Although I stayed close to the centres I visited, I was able to explore Manhattan, Brooklyn and San Francisco during evenings and weekends (figure 4).

I would like to extend my thanks to Professors J. Price, W. Jagust and D. Eidelberg for welcoming me to their departments. I am also very grateful for the support from my colleagues at the University College London Hospital. A special thanks to Dr J. Dickson for his encouragement and help.

REFERENCES
RESEARCH AND DEVELOPMENT IN 3D RADIATION DOSIMETRY

A.L. PALMER Head of Radiotherapy Physics, Portsmouth Hospitals NHS Trust

The need for practical and accurate 3D radiation dosimetry techniques is a priority in support of the rapidly advancing demands of modern high-precision radiation technology and clinical techniques. The IC3DDose conference is a premier forum held biennially to discuss these issues, with the key objectives to:

- enhance the quality and accuracy of radiation therapy treatment through improved clinical dosimetry;
- investigate and understand the dosimetric challenges of modern radiotherapy;
- discuss recent research and developments in 3D and advanced dosimetry, and
- energise and diversify dosimetry research and clinical practice by encouraging interaction and synergy between advanced, 3D and semi-3D dosimetry techniques.

The IC3DDose conference series originated as a specialist forum to discuss gel dosimetry, the 1st International Workshop on Radiation Therapy Gel Dosimetry being held in Kentucky in 1999. While maintaining a strong focus on gel dosimetry, and keeping to the ethos of discussing basic science through to clinical applications, the conference now includes a wide range of radiation dosimetry methods.

Overview of the conference

I was very fortunate to receive £1,000 of funding from the IPFM bursary award, along with financial support from Advanced Materials Group, Ashland Inc., Wayne, NJ, USA, to assist with the costs of presenting my own research into the application of Gafchromic EBT3 film dosimetry for HDR brachytherapy at the meeting. This is work involving the multichannel analysis of radiographic film to measure semi-3D dose distributions close to clinical HDR brachytherapy treatment applicators. This is also related to a proposed UK national audit of HDR brachytherapy.

The meeting was expertly organised by David Thwaites, Director of the Institute of Physics at the University of Sydney, Clive Baldock, Dean of the Faculty of Science at Macquarie University and their organising team. Even a major loss of power at the conference venue didn’t faze them (much) and the meeting resumed in an alternative 5* hotel after the briefest of pauses!

Around 120 people from across the world attended the 4-day conference, which comprised a full programme of 12 sessions with 12 invited speakers, topic reviews, over 90 individual proffered presentations and a poster session. There was also space for a couple of discussion sessions and a manufacturer/sponsor exhibition. All papers presented at IC3DDose will be published in the Journal of Physics: Conference Series in due course. This will include the invited reviews that were given at the conference: gel dosimetry (Kim McAuley, Queens University, Canada), the need for 3D dosimetry (Stine Korreman, Roskilde University, Denmark), solid state dosimetry (Peter Metcalfe, University of Wollongong, Australia), dosimetry with optical readout (Kevin Jordan, University of Western Ontario, Canada), 3D dosimetry applications (Mark Oldham, Duke University, USA), EPID pre-treatment dosimetry (Peter Greer, University of Newcastle, Australia), EPID in vivo dosimetry (Ben Mijnheer, NKI, The Netherlands), QA of external beam radiotherapy from 2D to 4D (Vladimir Feygelman, Moffitt Cancer Center, USA), scintillation dosimetry (Luc Beaulieu, CHUQ, Canada), MRI optical and x-ray CT evaluation (Yves de Deene, University of Ghent, Belgium, Simon Doran, Institute of Cancer Research, Sutton, and Andrew Jirasek, University of Victoria, Canada), dosimetry for audit and clinical trials (Tomas Kron, Peter MacCallum Cancer Centre, Australia), reliability of 3D gels (Yves de Deene), analysis of 3D dose and gamma evaluation (John Schreiner, SE Ontario Cancer Centre, Canada), dosimetry of CBCT (Jonathan Sykes, Leeds/St James’ Institute of Oncology), accuracy required and achievable (David Thwaites, University of Sydney, Australia, figure 1) and the dosimetry requirements for 4D radiotherapy (Paul Keall, University of Sydney, Australia).

Of course, with such a diverse and comprehensive meeting it is impossible to review all contributions in this meeting report, so below are a very limited selection of some of my highlights from the meeting.

Stine Korreman

Stine Korreman provided a review of the types of 3D dosimetry in clinical practice and usefully provided a new definition for terms. She divided 3D dosimetry into three categories; true 3D, semi-3D and virtual 3D. Virtual 3D involves the use of measurement arrays either before or after beam entry in the patient or phantom, whereas semi-3D involves the use of measurement arrays in phantoms mimicking the patient. True 3D involves the measurement of dose in a volume mimicking the patient. Korreman discussed the advantages and limitations of each category and gave a simple but often forgotten conclusion, that the choice of measurement method in a given case depends on the aim of the measurement, and all may be valid. It was suggested that virtual 3D dosimetry is the preferred future for clinical applications, verifying delivery is correct and enabling adaption decisions.

Fredrik Nordström

Fredrik Nordström (Skane University Hospital and Lund University, Sweden) presented a 4D dosimetry system. This included a method for calculation of 3D reference absorbed dose matrices at every control point of the delivery using a clinical treatment planning system. The gamma evaluation method was extended to incorporate the fourth dimension of the TPS calculated dose distributions, and termed ‘hyper-gamma’. The applications of the 4D dosimetry concept on pretreatment quality control and real-time in vivo dosimetry were demonstrated.

Peter Metcalfe

Peter Metcalfe presented a number of prototype novel radiation dosimeters
developed within the Centre for Medical Radiation Physics. This included two silicon array detectors, the magicplate and dose magnifying glass. The primary focus of these two detectors is high spatial and temporal resolution dosimetry for IMRT. The third detector discussed was the MOSkin, which is a high spatial resolution detector based on MOSFET technology, its primary role in in vivo dosimetry. The fourth detector system was the BrachyView, which is a high-resolution dose viewing system based on Medipix detector technology.

Unjin Yeo
Unjin Yeo (RMIT University, Australia) discussed the application of deformable gel dosimetry. Inter- and intra-fractional variation in anatomic structures is a significant challenge in contemporary radiotherapy and Yeo described the implementation of a novel deformable gel dosimetry system (termed ‘DEFGEL’) for application to external beam RT and brachytherapy experimental measurements. Complex/redistributed dose distributions due to applied deformations were readily observed and the discrepancies relative to a control case with an absence of deformation could be quantified. This work is proposed to have uses in the validation of deformable image registration algorithms, deformable dose calculation algorithms and quality assurance of motion compensation strategies in radiotherapy.

Boyd McCurdy
Boyd McCurdy (University of Manitoba, Canada) gave a valuable overview of EPID dosimetry, a-Si detectors, dosimetric characteristics and remaining limitations. There is strong continued interest in using EPID dosimeters for patient treatment verification. There are three distinct methods; non-transmission dosimetry, transmission/transit dosimetry and in vivo dosimetry, the latter being the determination of dose within the patient by measurements performed during treatment. McCurdy thought it is somewhat surprising that manufacturers have not yet provided commercial systems to fully implement EPID-based in vivo dosimetry.

Vladimir Feygelman
Vladimir Feygelman presented a review of historical dosimetric QC methods, including film and ion chambers in phantoms, and a vision of the required direction for the future, including methods for 3D and 4D dose reconstruction in the patient. Regarding patient-specific QA, he envisaged that the currently prevalent limited comparison of dose distributions in a phantom by gamma analysis will be eventually replaced by clinically meaningful patient dose analyses with improved sensitivity and specificity. In a larger sense, he envisaged ‘a future of QA built upon lessons from the rich history of “quality” as a science and philosophy’. This future will aim to improve quality (and ultimately reduce cost) via advanced commissioning processes that succeed in detecting and rooting out systematic errors upstream of patient treatment, thus reducing our reliance on, and the resource burden associated with, per-beam/per-plan inspection.

Alicia Cavan
Alicia Cavan (University of Canterbury, New Zealand, figure 2) provided one of a number of presentations that discussed alternative novel or emerging dosimetry methods, compared to established gel dosimetry. Alicia discussed a novel optical calorimetry dosimetry approach and its application with an HDR brachytherapy source. The technique of digital holographic interferometry (DHI) was applied to the measurement of radiation absorbed dose distribution in water. An optical interferometer has been developed that captures the small variations in the refractive index of water due to the radiation-induced temperature increase $\Delta T$. The absorbed dose $D$ is then determined with high temporal and spatial resolution using the calorimetric relation $D = c \Delta T$ (where $c$ is the specific heat capacity of water). The method is capable of time resolving 3D spatial calorimetry.

Simon Doran
Simon Doran (figure 3) provided a teaching review of optical CT techniques applied to Presage 3D dosimetry. The workflow for optical CT scanning including sample positioning, refractive index matching, the importance of apparatus cleanliness to the imaging process, the pre-scan and image reconstruction and post-processing were all described for successful dosimetry. Unfortunately, optical CT is not entirely a ‘push button’ technology process, although manufacturers and groups working in the field are moving steadily towards this position.

Tomas Kron
Tomas Kron provided a discussion of the dosimetry challenges and requirements for audit and clinical trials. The increasing complexity of radiotherapy planning and delivery makes audits challenging. While verification of absolute dose delivered at a reference point was the standard of external dosimetry audits two decades ago, this is often deemed inadequate for verification of treatment approaches such as IMRT and VMAT. As such, most dosimetry audit networks have successfully introduced more complex tests of dose delivery using anthropomorphic phantoms that can be imaged, planned and treated as a patient.
Scientists and Engineers in Medicine (ACPSEM). Conference photos reproduced courtesy of May Whitaker. The conference was sponsored by Elekta, ScandDos, Varian, New South Wales Government Department of Health, The University of Sydney Institute of Medical Physics, Macquarie University, CMSAlphatech, Sun Nuclear Corporation, Nuclotron, University of Wollongong, nitec, Medtech and the Australian College of Physical Scientists and Engineers in Medicine (ACPSEM).

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would. The new challenge is to adapt this approach to ever more diversified radiotherapy procedures with image guided/adaptive radiotherapy, motion management and brachytherapy being the focus of current research.

Benjamin Nelms

Benjamin Nelms (University of Wisconsin, USA), presented by Vladimir Feygelman, highlighted some ‘real-world’ examples of sensitivity failures of the 3 per cent/3 mm pass rate metric and published action levels when used in IMRT/VMAT system commissioning. It was proposed that these examples of observed ‘false negatives’ (insensitivities) point towards the inappropriateness of the 3 per cent/3 mm gamma passing rate metric as the basis for acceptance testing/commissioning of the IMRT/VMAT delivery chain.

Debates and discussions

There were a number of valuable debate sessions and discussions throughout the conference. One topic of debate was the lack of conversion of gel-based dosimetry into routine clinical practice over the last 10 years. There had certainly been a misguided view from the early days that 3D dosimetry would be required for every patient, but the current view seemed to be that the use of gels was still considered valuable for evaluation of new processes or techniques in radiotherapy centres. Gels and plastic dosimeters are indeed currently the only dosimeters that can fully measure a full 3D dose distribution. While some thought the challenge of using gel dosimeters was no more complex than other systems currently in routine use, several thought a huge effort was required for their set-up in individual clinics and that they are not practical except in established research departments. One particular problem with the use of gels is that they can only report integrated total dose of a treatment. Advanced treatments have a dynamic component and in order to track where errors may originate, temporal information on dose deposition is required. One particular advantage of gels is that they can be used within anthropomorphic phantoms and taken through the entire treatment chain.

It was proposed that it is not uncommon for people to be using 2D or 3D dosimetry tools and analysis methods without fully understanding the systems. One good example was in the application of gamma analysis and its widespread adoption in commercial systems. The ‘good feeling’ given by simplistic gamma passing rates has been accepted and perhaps led to its overuse, rather than a full investigation and evaluation of the clinical impacts of any dose differences between prescribed and delivered dose distributions.

The value of 2D compared to 3D dose distribution analysis, and the use of 2D and 3D gamma, were discussed. There were differences of opinion on whether 2D has a place or whether dosimetry should now be performed in 3D; the latter is certainly the dose actually delivered to the patient, but evidence of errors in 2D distributions being ‘averaged out’ in 3D analysis was presented.

The future of 3D dosimetry was of course discussed at various points in the conference. Although a complete consensus of opinion may not have been reached, all seemed to agree that the future of patient-specific QC for complex radiotherapy ideally lay in in vivo dosimetry measurement.

On the question of what is the ‘best’ dosimeter to use to assess the accuracy of treatment dose delivery, the conclusion was that all of the dosimetry systems discussed are likely to have a place for specific measurement situations, and no one dosimetry system would be optimum for all cases. The question of whether 2D (semi-3D) or 3D dosimetry is preferable was thought to be in some ways irrelevant or impossible to answer, since each system should be used when required for a particular measurement situation. It was, however, clear that if you are only using 2D measurement techniques and only looking at 2D gamma passing rates then your assessment is probably insufficient.

It was thought that a useful model may be regional groups of centres in which individual departments have expertise in particular measurement systems, and these being used within the region for particular measurements as may be necessary. The particular measurement system used should be matched to the information required, not just to the method that is available within the centre, and with full understanding of the limitations and any calculation algorithms used. When asked which the ‘best’ detector is, I (figure 4) believe that Ben Mijnheer summed up the feeling of the conference by stating: ‘the best thing to use is your brain’.

Summary

In a closing discussion, the following key areas for further development and research were identified: analysis tools and actual use of 3D measured dosimetry data, increased development of in vivo dosimetry, improved methods to communicate dosimetry data analysis to clinicians, commencement of widespread adaptive treatments and proper use of image guidance and the impacts these have on dosimetric QC assessments, methods for validation of adaptive dose registration, and improved decision making on dosimetry detectors and analysis metrics being used.
PEM was fully booked several weeks in for the IMRT verification meeting. Twenty-two abstracts had been submitted and all were to be presented either as talks or posters. Four manufacturers were displaying their varied equipment and IMRT verification was foremost in everyone’s minds, particularly as the Radiotherapy Innovation Fund had recently been announced to help expand the numbers treated with IMRT.

The meeting opened with Ran Mackay (Christie Hospital, Manchester) setting the scene with the arguments both for and against IMRT verification measurements. He used an analogy with the airline industry to consider what pre-treatment (pre-flight) checks do and don’t help us find. The conclusion was that by asking ‘to do or not to do’ we are asking the wrong question. The pre-treatment measurement is a good check of plan transfer, but will not catch all errors and that there are other ways to verify IMRT plans, not all of which need to be measurement based.

The next talk was by Catharine Clark (Royal Surrey Hospital, Guildford) and gave the survey results of the current status of IMRT verification in the UK (figure 1). The survey had been carried out in of 2012 and had responses from 53 UK centres. The data showed that all centres were making measurement-based verifications of some form and that two-thirds were also using software-based methods. The majority are planning to change their QA processes in the near future, with the changes being mainly in the numbers and types of measurements, but also in who was carrying them out.

Further talks followed from two centres who have been delivering IMRT for over a decade and focussed on how they had expanded their service without limiting the numbers (Carl Rowbottom, Christie Hospital, Manchester) and the problems and pitfalls they had encountered in deciding how to reduce measurements (Carole Meehan, Royal Marsden Hospital). Carl had taken the approach that systems of service delivery can have general similarities and quoted from the theory used by Edwards Deming in his book Out of the Crisis to look at the future of IMRT QA and work out processes that identify the errors which may have the greatest effects without too much of a time burden. Carole gave an overview of a decade of IMRT delivery at RMH and the decisions which had been taken along the way to reduce IMRT verification measurements. She gave examples from the very early days when IMRT verification measurements and analysis could take up to 8 hours per patient, through to the more recent use of portal dosimetry which can be done in a few minutes.

The next session was ‘What are we really looking at and what does it mean?’. Mohammad Hussein (Royal Surrey County Hospital, Guildford) began by looking at five different verification systems (including three arrays) and testing them with purposeful errors introduced into clinical plans. The survey had been carried out in of 2012 and had responses from 53 UK centres. The data showed that all centres were making measurement-based verifications of some form and that two-thirds were also using software-based methods. The majority are planning to change their QA processes in the near future, with the changes being mainly in the numbers and types of measurements, but also in who was carrying them out.

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(Christie Hospital, Manchester) then explained the pitfalls of using the gamma analysis technique, with a warning on taking care over how the plan is normalised, whether you use global or local gamma calculations, which regions of interest to look at and how the calculated and measured plans are aligned. His take-home message was to be consistent and not to simply transfer tolerances and passing criteria between different systems and techniques. Antony Carver (Clatterbridge Cancer Centre, Liverpool) then showed us what errors in IMRT plans might really mean in terms of clinical impact. He warned that even some small dose differences may result in unwanted TCP changes and recommended that a specific mean dose deviation should be applied to limit TCP changes in the event of a dose delivery error.

Lunch was held in the Geological Society’s library, where posters were viewed, opinions were sought, manufacturers were visited and beautiful maps of the rock strata of the British Isles were gazed at. We then focused our attention on the question ‘Can EPID solve all our problems?’.

Bas Nijsten (Maastro Clinic, The Netherlands) opened the session, giving us an insight as to what the future might hold. This group has been working on EPID (electronic portal imaging device) dosimetry for several years now and Bas gave an exciting glimpse of the kind of verification measurements we may use in the future, in particular the ability to backproject the measured beam fluence onto the CBCT of the day to create a ‘3D dosimetry of the day’. This opening talk was followed by three proffered papers from Barts and UCL on the developments they have made themselves in this area, showing that we are making good progress in the UK in this area too. There is no doubt that EPID will solve at least some of our problems.

The final session of the day was ‘Could a software solution be the answer?’. This session had six proffered papers from six different departments, discussing both in-house and commercial solutions. Andrew Williams (Norfolk and Norwich Hospital, Norwich) opened with a presentation on how they had managed to remove the physics bottleneck by using the software to mimic the point dose measurements from an array, allowing linac-based QA to be phased out. Christina Agnew (Northern Ireland Cancer Centre, Belfast) presented her work on the use of dynalog files from Varian machines to verify treatment plan delivery as well as assess the relationship between machine performance and plan complexity. All the speakers stressed the time difference required between software approaches compared with measurement-based approaches, with a clear direction for the future that software-based verification will allow a greater number of IMRT plans to pass through the physics department.

The day ended with a discussion. As all centres were considering their requirements for expanding IMRT with the opportunities afforded by the Radiotherapy Innovation Fund, this discussion was extensive and many wanted recommendations as to the best way forward. As ever the opinions were as varied as the products and the discussion continued to the very end of the session.

We would like to thank all the invited and proffered speakers and poster presenters for a very interesting and useful day!
The RSNA annual meeting is the largest medical meeting in the world, attracting approximately 60,000 attendees each year. It is held at McCormick Place, Chicago (figures 1 and 2), which just a few weeks before the 2012 annual meeting had hosted President Obama’s election night party. The meeting focuses on all aspects of medical imaging and there was a wide range of educational and scientific sessions on offer, from formal research presentations to educational exhibits and interactive workshops.

**Updating knowledge**

Having only previously attended much smaller conferences in the UK I was immediately awestruck by the scale of the event. Just walking from one end of the cavernous McCormick Place to the other took upwards of 15 minutes. The ‘programme in brief’, which named all the sessions at the conference, ran to over 400 pages! However, despite the potential difficulties in running such a huge operation most aspects of the meeting seemed well thought-out and well organised; from the constant stream of coaches ferrying people across the city via the reserved bus lanes to the use of dedicated smartphone applications to direct delegates to their chosen sessions.

I have recently become involved with the Sheffield 3D Imaging Lab, which aims to accelerate the uptake of advanced 3D visualisation and quantitative imaging techniques. Coming from a pure nuclear medicine background I was keen to update my knowledge on quantitative imaging in the other modalities. I therefore chose to focus much of my attention on the ‘refresher sessions’, which presented up-to-date reviews of certain areas within medical imaging. One such session of particular interest was entitled ‘Techniques for quantitative cancer imaging: current status’. The speakers gave an overview of current quantitative measurement techniques used in MRI, CT and PET and then went on to discuss the various benefits and issues associated with them. The main message that came across was that there is inherent variability in all modalities and although they can be very useful, quantitative measures should always be treated carefully. Binsheng Zhao (Columbia University Medical Center), for example, detailed all the factors that can influence test-retest variability in CT scans and highlighted data suggesting that repeat scanning of the same patient on the same CT scanner, just 15 minutes later, can lead to differences in linear tumour measurements of greater than 17 per cent. He therefore suggested that small changes in apparent tumour diameter may not be significant. Focusing on dynamic contrast enhanced MRI Gregory Karczmar (University of Chicago, USA) suggested that, at best, a reproducibility uncertainty of 10 per cent is possible for measurements of apparent diffusion coefficient (ADC). The final talk of the session, focussing on PET and standardised uptake value (SUV) measurements, was given by Paul Kinahan (University of Washington, USA). He
DRO Test Regions

- SUV values in general are either 0, 1.0, or 4.0, except
  - A single voxel in ROI 3 is set to 4.11
  - A single voxel in ROI 4 is set to -0.11
  - A checkerboard pattern is used to provide a deterministic test for calculation of the standard deviation in 2D (ROI 5) and 3D ROI6

FIGURE 3. Digital reference object with pre-defined regions of interest

FIGURE 4. Summary of results from the SUV measurement study

Results: 13 sites, 20 different display systems

blue = okay, yellow = ?, pink = borderline, red = wrong

| ROI Information | ROI 1 Min | ROI 1 Max | ROI 1 Mean | ROI 1 STD | ROI 2 Min | ROI 2 Max | ROI 2 Mean | ROI 2 STD | ROI 3 Min | ROI 3 Max | ROI 3 Mean | ROI 3 STD | ROI 4 Min | ROI 4 Max | ROI 4 Mean | ROI 4 STD | ROI 5 Min | ROI 5 Max | ROI 5 Mean | ROI 5 STD | ROI 6 Min | ROI 6 Max | ROI 6 Mean | ROI 6 STD |
|-----------------|-----------|-----------|------------|-----------|-----------|-----------|------------|-----------|-----------|-----------|------------|-----------|-----------|-----------|------------|-----------|-----------|-----------|------------|-----------|-----------|------------|-----------|-----------|------------|-----------|

results for each of the 6 ROIs
highlighted an important issue for anyone involved in providing a PET service – that there is often a tension between the needs of clinical protocols and research protocols. Clinical PET usually relies on visual interpretation and thus most PET scanners and PET protocols are set up with this in mind. However, research studies are often far more reliant on quantitative information, which may require more stringent administration protocols and camera quality assurance.

**Quantitative measuring**

One of the stated commitments of RSNA is to make radiology a more quantitative science. Thus, the Quantitative Imaging Biomarkers Alliance (QIBA) was established in 2007 to take forward this aim. During the annual meeting I attended a number of presentations and educational exhibits detailing the work of QIBA. Much of this was directly relevant to the Sheffield 3D Imaging Lab but also to anyone involved in taking quantitative measurements from medical images. One project with somewhat surprising results involved generating a digital reference object (i.e. an electronic phantom) with dimensions matching that of the standard NEMA PET image quality phantom. The image data was sent to 13 different sites with each asked to measure maximum, minimum and standard deviation SUV values for six pre-defined regions-of-interest (figure 3). The results received back were far from uniform (figure 4), suggesting that there may be variability in how SUV calculations are performed by different centres/systems.

Another interesting presentation related to the QIBA initiative was given by Nicholas Petrick (US Food and Drug Administration (FDA), Washington, DC, USA). Using results from a number of studies of realistic anthropomorphic phantoms he set out to explain the impact of different factors on the accuracy and precision of CT measures of tumour size. The type and location of the tumour nodule proved to have a substantial impact on results – spherical or lobular nodules in the centre of the lung, for example, were measured fairly accurately with 1D, 2D and semi-automated 3D measures. However, more complicated, ‘spliculated’ nodules produced much greater measurement errors, particularly when located next to pleural tissue and when using 1D and 2D measures. It was also highlighted that CT parameters, in particular slice thickness, can have a dramatic impact on quantitative measures of tumour size.

In addition to the refresher talks I also attended a number of ‘informatics’ sessions, many of which were dedicated to open-source image analysis software. As became apparent there are several open-source packages available, some of which have been developed over many years and have become extremely sophisticated. Such software could be of great benefit to any centres carrying out imaging research, particularly when the money available for buying expensive program licenses is so restricted. It was therefore very useful to be given a hands-on introduction to various platforms, including 3D Slicer, ImageJ and MRI Studio by the original developers of the code.

The RSNA annual meeting offers several different ways for researchers to present their work. Having submitted an abstract I was asked to produce an ‘informal scientific (poster) presentation’, which was an entirely new concept to me! As I later discovered such presentations are displayed on one of many TV screens for delegates to browse through at their leisure. An allotted time is then set aside for the author to discuss the research and answer any questions. Although my presentation was based on a specialist and very specific area in medical imaging – automatic tumour tracking using image registration – I was pleased to find at least a few people turned up to ask questions!

**Social events**

An unexpected benefit of having an abstract accepted by RSNA was that I was invited to a reception at the residence of the British Consul General. After checking that they had invited the right person I duly accepted the offer knowing that such an opportunity was unlikely to present itself again any time soon. The Consul’s residence turned out to be a very grand apartment on the 62nd floor of a building in downtown Chicago. With floor-to-ceiling glass panels spanning two levels, the apartment offered amazing views of the city, which were made all the more pleasurable by the champagne and canapés that were continually put in front of me. I’m not sure how much good I did for British industry but I would gladly come and make up the numbers again!

After the conference I set aside a day to explore Chicago further. Luckily the weather was unseasonably mild and dry. Other than the obligatory visit to the Willis Tower with its Skydeck (a glass box attached to the 103rd floor offering vertigo-inducing views) I was able to visit most of the downtown parks, including Millennium Park, which hosts the famous Cloud Gate sculpture (figure 5).

Overall, my visit to the RSNA annual meeting was thoroughly enjoyable and extremely useful, both for myself as a relative newcomer to quantitative imaging and to the Sheffield 3D Imaging Lab as a whole. I would like to thank IPEM for providing me with funding to make this trip possible.
The 12th International Conference on Electronic Patient Imaging took place in Sydney from 12th to 14th March 2012. The conference immediately drew my attention as it was highly relevant to my own area of research – using the EPID as a tool for in vivo dosimetry. I thought this would be an excellent opportunity to present my work at an international level and learn about other similar projects going on throughout the world. I was able to attend this conference thanks to an IPEM bursary and support from the developers of the software I had been working with, Math Resolutions.

A stimulating and intense programme had been planned, with invited lectures from internationally renowned speakers, refresher courses, proffered papers, scientific sessions, poster sessions, vendor Q&A, tutorials and a research symposium. The conference was held at the Four Points Sheraton Hotel at Darling Harbour, a great location to enjoy the lively city and lovely harbour (figure 1).

Day 1
Each day of the conference had its own theme: day 1 was ‘Real-time tumour localisation and adaptation in cancer radiotherapy’, day 2 was ‘Margins, adaptation, technology’ and day 3 was ‘In-room imaging, immobilisation, dosimetry’. The conference encompassed many different verification imaging techniques and the clinical applications of this modern technology, such as IGRT, SBRT and motion management.

Day 1 kicked off with a warm welcome from conference convenor May Whitaker (University of Sydney, Australia), followed by a brief introduction to real-time tumour localisation and adaption in radiotherapy by symposium chair Paul Keall (University of Sydney, Australia).

One of the many interesting talks on the first day was on multileaf collimator adaptation by Uwe Oelfke (German Cancer Research Center (DKFZ), Heidelberg, Germany). He described a dynamic control system which enables real-time tracking of moving target volumes to improve delivery accuracy.
Through continuous optimisation using MLC control and a verification loops, the aperture dynamically changes shape and size during treatment; ‘breathing leaves’. The algorithms calculate new leaf positions based on target information provided online to the system, using MLC latency to predict the future position. The new tracking system has not yet been used on patients, but preliminary results have shown increased accuracy and quality of treatment delivery. In a clinical situation, the target motion of each patient would have to be assessed before the radiation delivery.

Day 2
One of the highlights of day 2 was a lecture on CBCT for intra-fraction monitoring and adaptive RT by keynote speaker Marcel van Herk (Netherlands Cancer Institute (NKI), Amsterdam, The Netherlands). He began by emphasising the importance of appreciating and selecting the appropriate frequency for imaging: are we looking at weekly changes, daily set-up errors, minute-by-minute before and after differences, or on the scale of real time? IGRT is a compromise between speed and quality; 2D bone/marker matching is a quick and simple check, 3D soft tissue matching is often more informative and appropriate, real-time 4D motion tracking involves complex reconstruction, and full adaptive radiotherapy can involve taking account of many days’ scans to adapt and deform the treatment delivery accordingly. 2D planar imaging, although quickest, cannot detect tumour shrinkage, weight loss, tumour positional changes, marker migration or normal tissue changes. Intrafraction imaging can provide information on respiratory motion, baseline tumour shifts, bladder filling, peristalsis and patient movement for which algorithms can be constructed or filters applied, for example using the Amsterdam shroud technique. This was all very useful food for thought.

Marcel went on to speak about a novel imaging solution being investigated at NKI: simultaneous CBCT and VMAT delivery. Ultimately a 4D validation scan is acquired during the VMAT treatment delivery arc, allowing GTV tumour motion to be assessed with respect to the PTV margin. There are approximately 1,000 projections per arc, corresponding to a CBCT dose of 1.5 cGy. Problems they encountered using concurrent CBCT-VMAT included scatter from the treatment beam, line artefacts on the CBCT due to accelerator pulses and the increased noise. To overcome this, a microcontroller was used to alternate image acquisition to sync with accelerator pulses. The images were filtered according to beam on/off acquisitions and a derived scatter correction was applied. By examining the differential motion, an average patient model could be established to provide a model for adaptive RT.

Day 3
On day 3, Boyd McCurdy (University of Manitoba, Canada) gave an excellent refresher on EPID-based patient dose verification. There are several challenges encountered when attempting to use the EPID as a dosimeter: modern a-Si panels are not water equivalent and therefore due to the metal and phosphor screen, the panels are more responsive to low energy x-rays; the EPID housing generates a self-scattering component; older camera-based systems had issues with optical glare; there is non-uniform backscatter due to the arm; the effect of patient scatter; ghosting and image lag; sag of the imager with gravity at non-zero gantry angles; incomplete signal acquisition during cine mode (63 ms delay), and difficulty precisely determining gantry angles (±3°). Many of these effects can and have been modelled by various groups around the world in order to successfully calculate absolute dose via simulated back projection. Using the EPID in this way enables dose calculations using the ‘exit’ radiation images acquired during the patient treatment to pick up detectable errors, including machine (wedge, missing segments, MLC, leaf sequences, collimator angle, beam flatness/symmetry, output), plan (transmission through leaves, gradients, MLC modelling, plan transfer) and patient (table, immobilisation, anatomical movement and changes, wrong patient!)
errors. Several errors have been caught and documented using this method, differences mainly due to anatomical changes, and in one case, a discovery that incorrect tongue and groove parameters had been entered into the TPS.

David Thwaites (University of Sydney, Australia) then gave an overview of a selection of products available for performing on-board in vivo dosimetry. This is evidently a market that is rapidly developing, with increasing worldwide pressure for a solution for patient dose check. Following on from this was a fascinating series of preferred papers on the topic of novel in vivo dosimetry and approaches. These included: Boyd McCurdy expanding upon his earlier session by describing an accurate method for patient dose reconstruction from on-treatment EPID images; Brad Oborn (University of Wollongong, Australia) on a Geant4 Monte Carlo simulation method for IMRT verification; Lei Xing (Stanford University, California, USA) on direct measurement of leaf positions with EPID for verification of IMRT segments, and Tanya Kairn (Queensland University of Technology, Brisbane, Australia) on in vivo EPID dosimetry in head and neck cases: a simple technique using the TPS to predict dose at the EPID plane.

My e-poster presentation

My own e-poster presentation was along a similar theme: ‘In vivo dosimetry using “Dosimetry Check” – a commercial EPID-based transit dosimetry solution’. The concept of an e-poster was new to me but worked well, with a laptop workstation section set up in the exhibition hall, allowing delegates the freedom to peruse the posters at their leisure. There was a lot of interest in my poster and I gave several detailed presentations to individuals and small groups. Having been involved in the initial beta testing of the in vivo module of the dosimetry check system and commissioning it over two different sites (Edinburgh Cancer Centre and Royal Surrey County Hospital), I was able to present a thorough overview of the system and my latest patient results. I briefly explained the rationale behind performing in vivo dosimetry (with specific reference to Towards Safer Radiotherapy), the advantages of using the EPID over conventional methods, the commissioning process, the clinical pathway and the calculation model. I presented an example VMAT patient case study and the overall results over 47 IMRT and VMAT patients indicating that the system was calculating the mean dose to the primary PTV to within 0.5 per cent (±2.3 per cent) compared with the TPS (figures 2 and 3). Using the EPID to perform in vivo dose calculations in this way simulates the full clinical situation and provides the final verification of the dose being received by the patient.

The conference was an intense, informative and educational meeting with a stellar cast of speakers and was an invaluable experience for me, thanks to the IPEM bursary. The next EPI conference will be held in Aarhus, Denmark, in 2014 and I thoroughly recommend this to anyone interested in verification imaging in the radiotherapy community, as this was a truly excellent conference.

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Welcome to the second 2013 issue of ‘Book Reviews’. There are three textbook reviews in this issue covering the medical physics genre. A list of the reviewed titles with reviewers can be found in Table 1.

As with each Scope issue, there are a number of new medical physics textbooks in the ‘Just Published’ section such as 4D Modelling and Estimation of Respiratory Motion for Radiation Therapy, which illustrates registration and motion algorithms for the interpretation of complex 4D medical image sequences, and Interstitial Prostate Brachytherapy, which provides a comprehensive overview of innovations in LDR, HDR and PDR interstitial brachytherapy for the management of local or locally advanced prostate cancer. You will find some interesting reports listed in the ‘New Reports’ section, such as ‘Practical Guidance on Thyroid Monitoring for Radioiodine Using Hand-held Instruments’.

Readers interested in reviewing listed/unlisted books should get in touch with me, so I can arrange to send you the required material directly from the publisher. Note that some of the new reports are freely available to download (as PDFs) from the respective websites.

Urgent request for reviewers

We really do require more book reviewers to maintain a steady stream of reviews for Scope. Please drop me an email if you are interested in becoming a reviewer.

Apart from the numerous benefits of reviewing, it can also count towards your CPD which is a requirement for those registered with the HCPC.

Usman I. Lula is a Principal Clinical Scientist based in the Radiotherapy Planning section (Radiotherapy Physics QEMC) at the Queen Elizabeth Hospital, University Hospitals Birmingham NHS Foundation Trust, UK.

Email: usman.lula@u hb.nhs.uk

Webb’s Physics of Medical Imaging

There has been a very long wait for the second edition of this book, which was first published in 1988. There is a new editor, but the consistent editing approach of the original is retained, leading to a cohesive textbook, in spite of the 25 contributors. An attraction of this book, compared with others that have a similar coverage, is that the material was originally aimed at postgraduate engineers and physicists rather than at radiologists. So, there is a rigorous approach to mathematics throughout, image processing and the mathematics of image formation are included explicitly, and for some modalities there is a physics-eye view of quality assurance and phantoms. For this reason, readership some basic knowledge is assumed – readers without, for example, a degree in physics may need supplementary material to bring them up to speed.

The editor’s aim was to keep the content in one, manageable book while retaining accessibility for student use. Overall, in spite of the many new developments to be included, the challenge has been met. Chapters on the main imaging modalities have been overhauled, with the almost historical-looking images of the first edition replaced with up-to-date examples. Chapters on infrared and electrical impedance imaging have been retained, the diaphanography chapter has been replaced by one on optical imaging and the medical image processing content has been extended. There is a lot covered and the index is, perhaps sensibly, not comprehensive. The contents listings at the start of each chapter are more useful. The final chapter makes interesting reading as it encourages readers to step out from modality ‘silos’ to compare and contrast imaging modalities and their applications. Legislation and regulatory issues are not covered.

Although the content has been updated, the book has a very similar appearance to the 1988 version, with single column text and interspersed illustrations. It follows an old-style textbook approach: there are no boxes highlighting points of interest, no worked examples and no colour enhancements to greyscale diagrams.

There are no questions or exercises for the reader. One addition is the inclusion of colour illustrations; these are grouped together in sets of colour plates. The book has a scholarly feel – the lists of references at the end of each chapter are longer than would be expected in a textbook. These need not be consulted immediately, but they future-proof the purchase as they may turn out to be valuable later in the reader’s career.

A Kindle version is available – it can be read using apps and tablets but not with a basic Kindle device. I tried a sample using the PC app. The book’s pages are reproduced, they can be zoomed and you can add notes. However, the app does not allow the text to be searched, which would have been a valuable feature.

This book is excellent value for money and is a strong contender as a textbook for masters level courses. Buy one early on, and this is a book that you’ll consult throughout your career.

<table>
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<th>Book title</th>
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<td>Monte Carlo Calculations in Nuclear Medicine</td>
<td>David Hall</td>
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<tr>
<td>Digital Mammography: A Practical Approach</td>
<td>Lisa Davenport</td>
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TABLE 1
**Monte Carlo Calculations in Nuclear Medicine**

The first edition of this book, published in 1998, was one of the first to describe applications of Monte Carlo methods in nuclear medicine, and 15 years on this largely changed, or rewritten, second edition describes major changes in programs and methods, though the editors still recommend having both editions!

The book contains five background chapters, six on specific Monte Carlo codes, two on scatter correction in SPECT and PET, and three on applications. It is not too mathematical, but is fairly dense and rewards close reading.

The background chapters, on Monte Carlo methods, variance reduction techniques, anthropomorphic phantoms, and gamma camera and PET basics, are clear and well referenced, with areas such as Bremsstrahlung imaging and solid state detectors added since the first edition. Variance reduction techniques – the methods and approximations used to deal with the inefficiency of PET and SPECT – are well covered, and these methods are referred to extensively in later chapters. Developments in anthropomorphic phantoms are also particularly well described throughout the text.

The chapters on Monte Carlo codes which follow are the heart of the book. The methods covered – two general purpose high-energy physics codes EGS and MCNP, SIMIND for SPECT, SimSET and GATE for SPECT and PET, and the analytic PET simulator ASIM – are described by some of the lead developers and users. In all cases a wealth of information is provided which would allow any interested user to decide between the codes, and the chapters are up-to-date and complete. There are some differences in terminology, for example importance sampling instead of variance reduction in one chapter, and some differences in coverage, but all methods are well referenced and have more information available online.

The chapters on system design and image quality would be very useful in developing research protocols.

**Digital Mammography: A Practical Approach**

Perhaps you are emerging, bleary eyed and staggering slightly, into a bright new dawn following all your digital mammography commissioning. Maybe you have yet to stumble into the whirlwind. Or maybe you can fly through your routine tests without checking the work instructions every 3 seconds. Wherever you are in your digital mammography journey, if you have time to pause and reflect, you will love this book.

I haven’t checked it if there are comparable books out there but this one is pretty much perfect. It is beautiful and glossy and feels expensive (that’ll be because it is expensive…). The book is a compendium of chapters by American physicists and radiologists. Chapters are presented in scientific paper format with discussion and references at the end of each. A couple of the chapters repeat what the author’s own work.

Dr Elizabeth Berry is the Director of Elizabeth Berry Ltd (Berwickshire) and specialises in medical imaging. She tutors for the Open University and is a Fellow of both IPEM and IoP.

Dr David Hall is Head of the Nuclear Medicine Physics Section, Department of Medical Physics and Bioengineering, University Hospitals Bristol NHS Foundation Trust, and is based at the Nuclear Medicine Imaging Department, Bristol Royal Infirmary, Bristol, UK.

**WEBB’S PHYSICS OF MEDICAL IMAGING (2ND EDITION)**
M. A. Flower (Editor)
Publisher: CRC Press
ISBN: 978-0-7503-0573-0
Format: Hardback
Pages: 864

**MONTE CARLO CALCULATIONS IN NUCLEAR MEDICINE – APPLICATIONS IN DIAGNOSTIC IMAGING (2ND EDITION)**
Michael Ljungberg, Sven-Eric Strand, Michael A. King (Editors)
Publisher: CRC Press, Taylor and Francis Group, Boca Raton, London and New York
Format: Hardback
Pages: 357
Price (publisher’s website): £82

**SCOPE | JUNE 2013 | 49**
DIGITAL MAMMOGRAPHY: A PRACTICAL APPROACH
GARY J. WHITMAN, TAMARA MINER
HAYGOOD
Publisher: Cambridge University Press
ISBN: 978-0-521-76372-1
Format: Hardback
Pages: 192
Price: £65 (US$99)

BOOK REVIEWS

> comprehensive and (as the subtitle says) practical view of digital mammography.

After an introductory paragraph or so we go straight into the image quality metrics section. This is ideal for refreshing your mind on MTF and what that CDMAM phantom is actually doing. However, beyond the traditional physics bits on detectors, image processing and quantitative image testing, I found this book to be especially useful for seeing the broader picture; the bits that medical physicists don’t get to see so much. This includes the presentation and radiologists’ interpretations of images, PACS (useful stuff applicable to all modalities), efficacy of digital breast screening, artefacts, a lengthy and well-illustrated chapter on clinical cases, and a chapter on procedures such as stereo breast biopsy. There are also the expected chapters on developments in tomosynthesis and breast CT.

Being an American book, all the regulations and guidance referred to are American and the issues regarding availability of breast screening to the population are different to the UK, but I didn’t find this a hindrance to the book’s usefulness. I would definitely recommend this book to anyone who not only wants clear explanations of digital mammography technology but also a broader understanding of all the practical issues.

If, like me, you have a tendency to moan about having to drive for an hour through the snow to a remote, boiling hot caravan, not daring to fiddle with the air-con for fear of breaking the mammo set, this book may help you see the error of your ways.

Lisa Davenport is a Clinical Scientist specialising in Radiation Protection and is based at the Radiation Physics section of Bradford Teaching Hospitals NHS Foundation Trust, Bradford (UK)

Just Published!
Introduction to Nuclear Science, 2nd edition by Jeff C. Bryan (Taylor & Francis) provides an introduction to nuclear chemistry and physics, from basic concepts to nuclear power and medical applications. There are new chapters which cover nuclear reactor types, their safety systems and recent accidents such as the one in Fukushima, Japan. This book is aimed at those studying nuclear medicine and radiation therapy.

Physics-based Deformable Models by Dimitris N. Metaxas (Springer) presents a systematic physics-based framework for modelling rigid, articulated and deformable objects, their interaction with the physical world and the estimate of their shape and motion from visual data. It presents a large variety of methods and associated experiments in computer vision, graphics and medical imaging and is suitable for students in medical imaging and biomedical engineering.

There are new chapters which cover nuclear reactor types, their safety systems and recent accidents such as the one in Fukushima, Japan

Exciting Interdisciplinary Physics by Walter Greiner (Springer) provides a major focus on nuclear structure physics, quantum electrodynamics of strong fields. It covers areas that include high-energy physics, astrophysics and medical physics (heavy ion tumour therapy).

Medical Imaging Technology by Mark A. Haidekker (Springer) provides an introduction into the principles of image formation of key medical imaging modalities. This includes CT, MRI, ultrasound and radionuclide imaging. This textbook is aimed at biomedical imaging students and can act as a reference and self-study guide for more specialised in-depth studies.

The History of Radiology by Adrian M. K. Thomas and Arpan K. Banerjee (OUP) is a beautifully illustrated review of the remarkable developments within radiology and the scientists and pioneers who were involved. The engaging and authoritative history will appeal to a wide audience including medical students, medical physicists, medical historians and radiographers.

Interstitial Prostate Brachytherapy by Gyorgy Kovacs and Peter Hoskin (Springer) is the first interdisciplinary book on the subject providing a comprehensive overview of innovations in LDR, HDR and PDR interstitial brachytherapy for the management of local or locally advanced prostate cancer. All chapters have been written by internationally recognised experts who for more than a decade have formed the teaching staff responsible for the successful GEC-ESTRO/EAU prostate brachytherapy teaching course.

4D Modelling and Estimation of Respiratory Motion for Radiation Therapy by Jan Ehrhardt and Cristian Lorenz (Springer) illustrates registration and motion algorithms for the interpretation of complex 4D medical image sequences. Different 4D CT image acquisition techniques and conceptually different motion estimation algorithms are presented. This book is aimed at biomedical engineers, medical physicists, researchers and physicians working in the fields of medical image analysis, radiology and radiation therapy.

Quantifying Morphology and Physiology of the Human Body using MRI by L. Tugan Muftuler (Taylor & Francis) reviews various MRI techniques for obtaining quantitative and physiological information on the human body. It compares and contrasts several different applications of MR in quantitative research including data acquisition, processing and analysis/ interpretation.
Reviews of textbooks recently published on medical physics, and details of newly published books and reports

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## NEW REPORTS

- **Non-HEU Production Technologies for Mo-99 and Tc-99m.** IAEA Nuclear Energy Series, STI/PUB/1589; 2013.
- **Neutron Generators for Analytical Purposes.** IAEA Radiation Technology Reports, Number 1, STI/PUB/1535; 2012.
- **Human Radiosensitivity.** HPA RCE 21; March 2013.
- **Practical Guidance on Thyroid Monitoring for Radioiodine Using Hand-held Instruments.** HPA-CRCE-044; February 2013.
- **Full Quarterly Radiotherapy Error Data Analysis for Periods August 2011 to July 2012.** HPA Update, Issue 7; January 2013.
- **IVD and Patient Safety Considerations. Presentation at BIR; December 2012.**
- **Learning from Errors – The National Picture. Presentation at BIR; September 2012.**
- **Radiation Dosimetry and Image Quality Assessment in Computed Tomography. ICRU Report Number 87, Volume 12, Number 1; 2013.**
- **Quantification and Reporting of Low-dose and Other Heterogeneous Exposures. ICRU Report Number 86; 2013.**
- **Safety Requirements for Electrical Equipment for Measurement, Control and Laboratory Use – Part 2-201: Particular Requirements for Control Equipment.** IEC 61010-2-201 ed1.0; March 2013.
- **Information Technology: Programming Languages – Guidance to Avoiding Vulnerabilities in Programming Languages through Language Selection and Use.** ISO/IEC/TR 24772 ed2.0; March 2013.
- **Amendment 1 – Ultrasoundics – Hydrophones – Part 3: Properties of Hydrophones for Ultrasonic Fields up to 40 MHz.** Project IEC 62127-3-am1 ed1.0; March 2013.
- **Ultrasonics: Physiotherapy Systems – Field Specifications and Methods of Measurement in the Frequency Range 0.5 MHz to 5 MHz.** IEC 61689 ed3.0; February 2013.

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Here have been many ‘radiation leak’ incidents over the years, but for sheer magnification the following story must be hard to beat (figure 1). Indeed, it may be difficult to believe, but it is entirely factual. It relates to an event at the National Physical Laboratory in Teddington in 1984.

Whilst monitoring an old laboratory building once used for radiochemical work, including the analysis of uranium ore, a small patch of radioactivity was detected on the concrete floor. The radiation level, due to S-rays (which scarcely penetrate a piece of paper), was trivial but nevertheless correctly reported to management. In accordance with good practice, the building concerned was temporarily closed as a precautionary measure. Unfortunately this meant that the staff concerned could not retrieve their belongings. As a result subsequent conversations between them at the nearby Queen Dowager public house were by chance overheard and reached the ears of the press. Sensing a ‘radiation leak’ story, the press proceeded to ferret for information from all possible sources, from the landlord of the public house to Whitehall departments who had yet to hear about the issue. The S-activity in question was bound to the host surface and therefore could not be ingested or inhaled. In fact, from the standpoint of the public, the matter was manifestly irrelevant.

However, on Thursday 19th January 1984, the Daily Express, claiming an ‘exclusive’, ‘revealed all’ with an incredible and utterly irresponsible banner headline on its front page where it claimed a great cover-up had masked an ‘atom leak’ and that it was not safe for families near the ‘secret’ laboratory.

Contents of the report

A 2-page report included the following points:

- A radiation leak shut down part of a secret research laboratory in the London suburbs.
- Uranium, which could kill, was found in a building close to homes. The laboratory is very close to residential streets and a school.
- Radiation levels 100 times greater than background levels were found in the building (attributed to an employee who ‘must remain anonymous’).
- Too much radiation can lead to cancer. They purport that these levels would cause 100 times more cancers in the population (attributed to Dr William Connel of ‘Friends of the Earth’).
- Public concern will be increased about siting laboratories close to houses and schools.
- People in North London are already campaigning against plans to switch research on dangerous diseases from Porton Down, Wiltshire, to Colindale. This incident may anger them further.

The following day, 20th January, the Daily Express ran another article which claimed that six radiation workers were at risk from a new leak and there would be a top level investigation at Aldermaston. It name-checks the leak of the previous day and the associated ‘cover-up’.

Such stories exaggerate, distort or falsify information in a way that makes captivating reading but undermines trust in the institutions.

Further ‘stories’

This led to an editorial in the same issue headed ‘Away with this secrecy’. Attacking the nuclear energy business, it claimed that its ‘record of cover ups is appalling. Small wonder that it provides grist for the scaremongering mills of sensationalist filmmakers’.

On the same day, 20th January, the Daily Mirror also reported the Aldermaston story, together with an editorial headed ‘The secret horror’, with references to Aldermaston, NPL and Winscale – thereby equating NPL with other centres whose activities do not enjoy whole-hearted public support (as with Porton Down above).

It is of course this type of journalism – known as ‘horror story’ writing – which is appalling. Such stories exaggerate, distort or falsify information in a way that makes captivating reading but, at the same time, undermines trust in the institutions concerned, particularly scientific ones.

In the present instance, the impact at NPL of such tabloid sensational scare mongering was dramatic:

- In the late evening (18th January) prior to the Daily Express story, NPL staff were told that the laboratory had been shut down for a radiation leak.

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W. Alan Jennings (Former Head, Division of Radiation Science, National Physical Laboratory) on an event reported in the Daily Express in January 1984
Express’s so-called ‘revelations’, the media, including 
BBC and ITV television crews, besieged the NPL 
gates, presumably through some planned leak or tip 
off, to witness events at first hand.

First thing in the morning of the 19th January, Dr 
Paul Dean, Director of NPL, and others were urgently 
summoned to Whitehall by Norman Tebbit, Secretary 
of State, to brief Kenneth Baker, the Minister directly 
responsible for the NPL, to respond to a private 
notice question tabled for that afternoon by Toby 
Jessel, the MP for Twickenham, in whose 
constituency the laboratory was sited. A House of 
Lords question was also tabled on that day. The 
discussion is recorded in Hansard (19th January). 
Factual answers were given to the Daily Express 
allegations in order to reassure MPs, some of whom 
referred to levels of anxiety in their constituencies.

At Kenneth Baker’s request, as Minister for 
Information Technology, a public meeting was held 
involving local residents and other interested 
parties.

The forthcoming laboratory children’s Christmas 
party, normally held in late January, was cancelled.

‘STOP MAKING ATOM BOMBS’ was daubed on a 
library window facing a public road which crosses the 
laboratory grounds.

The impact of the whole episode was such that 
even property values in neighbouring streets fell, 
and was illustrated in JAK’s cartoon in the Evening 
Standard (figure 2).

It took some months for the situation to return to 
normal. Once the public mind is infected with some 
irrational belief, it is indeed very hard to control.
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