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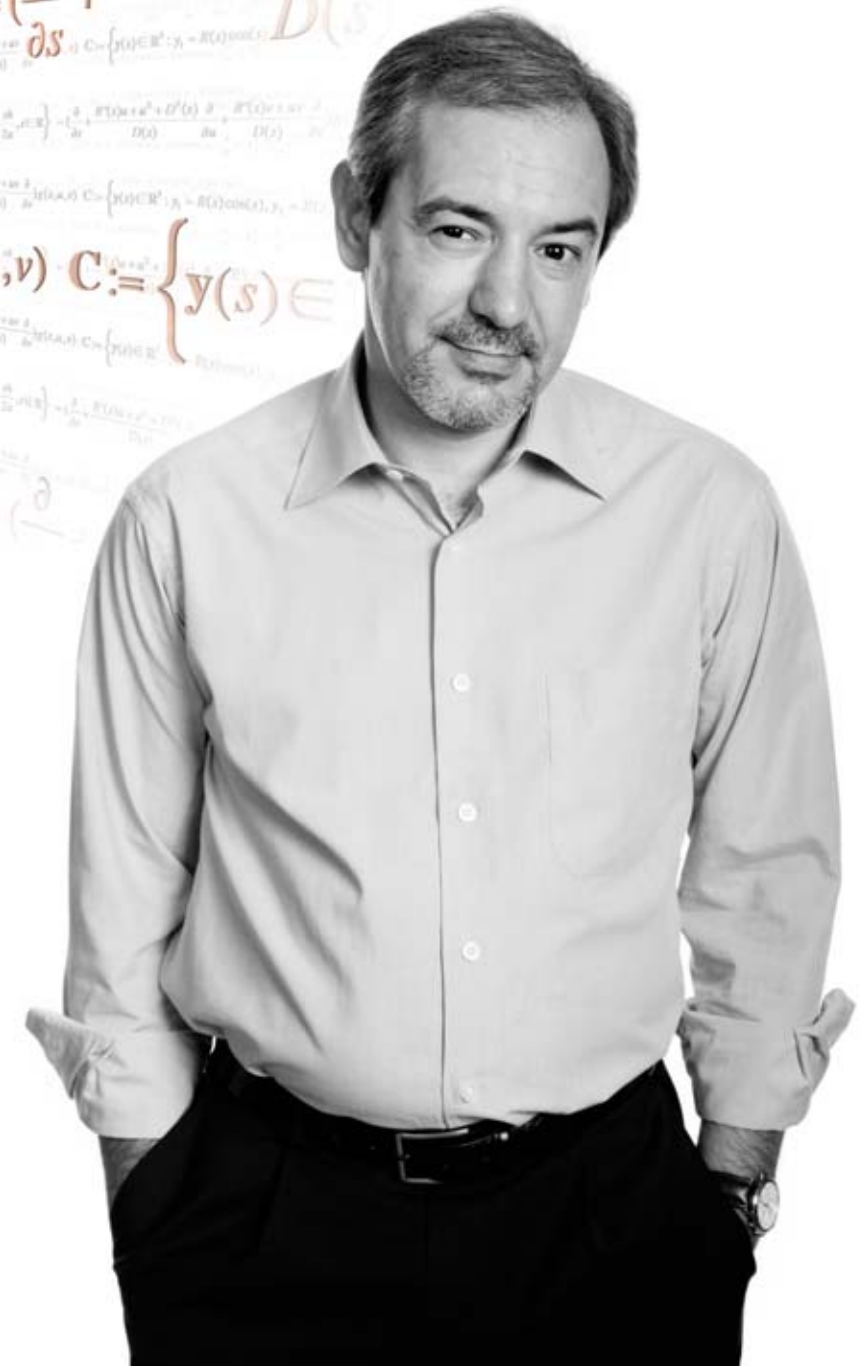

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Editor: **Hazel Edwards, Consultant Sonographer, Norwich Radiology Academy, Norfolk & Norwich University Hospital**

Publisher: **Dominic Deeson**

Designers: **Deeson Create**

Display advertising: **Rob Aspin**
Tel: 01795 542402

Published by: **Deeson Group Ltd**
www.deeson.co.uk

Printed by: **MWL Print Group, Pontypool**

Imaging & Oncology is a publication of The Society and College of Radiographers
207 Providence Square, Mill Street, London SE1 2EW
Tel: 020 7740 7200 · Fax: 020 7740 7204 · E-mail: imagingandoncology@sor.org

ISBN 9871 871101 58 1

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EDITORIAL

A change for the better

Welcome to the 2011 issue of *Imaging & Oncology*, which features 10 articles on some of the hottest topics affecting our professions. In addition to their contemporary relevance, each one describes, calls for, or predicts change.

We begin with three cutting-edge radiotherapy topics describing revolutionary advances in technique. Two papers by leading academics from the United Kingdom and the United States discuss the changing face of radiographic education. There are also articles discussing how imaging services for stroke/TIA must be improved and how uterine artery embolisation must become more widely available.

Hiorns takes us on a step-by-step guide through the new Imaging Services Accreditation Scheme, and provides helpful tips for others who will undoubtedly be preparing to embark on the same process. From nuclear medicine, a team describes the importance of sentinel node detection in breast cancer, and finally, Curtin predicts the likely impact recently published cardiac guidelines may have on CT departments.

Some years ago, Queen Elizabeth II commented, "I sometimes sense the world is changing too fast for its inhabitants, at least for us older ones." Nowhere is this more obvious than within the world of imaging and oncology. But radiographers, radiologists, physicists, and educationalists have not only kept pace with change but are, of course, responsible for accelerating it, as demonstrated in the following pages.

Whether in terms of improving patient survival rates, developing better treatment outcomes, or setting higher practice standards, all describe change for the better.

See what you think please and read on.

Hazel Edwards

Hazel Edwards

FOREWORD

Back to the future

My term as President of the Society and College of Radiographers has enabled me to look backwards and forwards on the development of our profession. In August 2010 we celebrated 90 years since the founding of the Society of Radiographers. It is not until you look back to where and when we started do you realise how far we have come in such a short time.

Now in 2011 we are celebrating the Year of Radiotherapy, which is an initiative to raise public awareness of the value of radiotherapy in the treatment of cancer. This is a project where a multi-professional group including the Society of Radiographers, the Royal College of Radiologists, Cancer Care UK, the Institute of Physics and Engineering in Medicine, the National Health Service, and representatives from all of the four countries within the United Kingdom have worked together towards a common goal.

An excellent example of what can be achieved when everyone works together for the good of our patients.

Both events encouraged me to reflect on the advances of both the technology and the professional practice which enables radiographers both diagnostic and therapeutic to contribute greatly to increased patient care and service delivery. In addition, both celebrations have been set against challenging times, economically and politically – but never forget challenges present great opportunities.

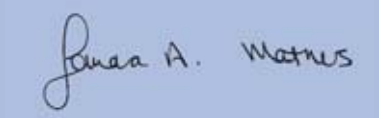
In the delivery of a quality, patient centred service, no profession can work in isolation; there is so much to be learned from each other. Working in multi-professional teams is the way ahead: each valuing the others' contribution to the overall package of care.

We have chosen dynamic careers in imaging...ever changing and moving forward. This annual publication, Imaging and Oncology 2011, now in its seventh year, always challenges our thoughts and perceptions, and this year is no exception.

I congratulate the editor for gathering together such an interesting and varied selection of papers covering education and professional practice, future trends, and challenges from both a UK and international perspective. And all this not only for diagnostic and therapeutic radiographers, but also for our fellow colleagues in the imaging and oncology professions.

So take time, sit down and savour this cornucopia of papers, all written for you by leaders in their respective fields. Please read the articles which are on topics which are new to you: there is nothing like new knowledge to challenge your established ways of thinking.

What ever your experience, I hope the papers provide food for thought, and inspire you for the future.



Sandie Mathers
President
The Society and College of Radiographers


THE VALUE AND FUTURE OF PROTON RADIOTHERAPY IN THE UK
CARL ROWBOTTOM
2011
THE YEAR OF RADIOTHERAPY

Should proton therapy be available in the UK? What are the barriers that must be overcome first?

INTRODUCTION

The concept of treating cancer patients with protons was first suggested by Robert R Wilson in a paper published in 1946[1]. Initially, patient treatments were performed with particle accelerators built for physics research, most notably at the Berkeley Laboratory in the USA and Uppsala in Sweden in the mid 1950s. It took another 35 years before a purpose built hospital proton facility was built with the Loma Linda University Medical Center in Loma Linda, California in 1990. Recent years have seen a growth in the number of proton radiotherapy treatment centres either opening or in the planning stage with nearly 30 centres worldwide in operation at the end of 2010.

The potential advantage of protons for radiotherapy treatment can clearly be seen from the depth dose characteristics of photons and protons using a spread-out Bragg peak (Figure 1). Proton radiotherapy treatments have the potential to reduce the integral radiation dose received by the patient, and to deliver lower doses to normal tissue proximal to the tumour compared to traditional photon radiotherapy treatments.

For proton radiotherapy a high energy accelerator capable of accelerating protons to at least 230MeV is required to provide sufficiently energetic protons to penetrate to the centre of body. The particle accelerator will either be a cyclotron or synchrotron and the choice has an effect on the performance parameters of the clinical beam. A cyclotron can produce a high current beam of one energy, the maximum required. For clinical treatments, the beam energy must be degraded to provide the range of energies required to produce a spread-out Bragg peak for treatment.

The degrading can be performed very quickly but reduces the current of the proton beam, which can be a problem when treating at lower energies. Synchrotrons generally operate at a lower current but can accelerate to different energies and so beams do not require degrading. As a result, they can produce beams with a better energy resolution but the time to switch between energies is longer. They are generally more complex machines and so more expensive and operate at a lower beam current.

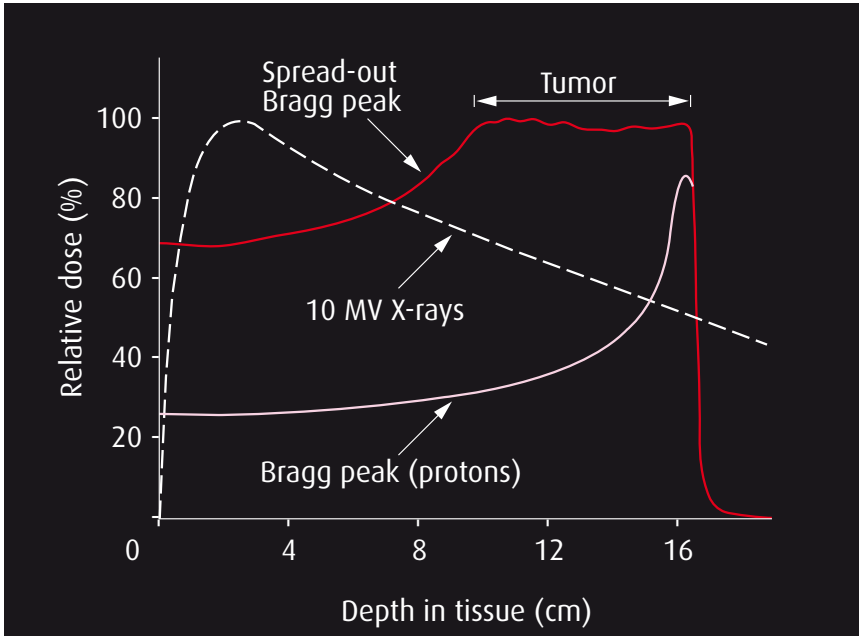


Figure 1. Depth dose characteristics in tissue of a single Bragg peak (pink), a spread-out Bragg Peak (red), which consists of different energy Bragg peaks added together, and a 10MV x-ray beam (dashed). Taken from Technology Insight: proton beam radiotherapy for treatment in pediatric brain tumors Torunn I Yock and Nancy J Tarbell, Nature Clinical Practice Oncology (2004) 1, 97-103 (reproduced with permission).

The high cost of the particle accelerator for proton radiotherapy means treatment centres run multiple treatment rooms off a single accelerator. Typically, between three and five rooms can be serviced. The limiting factor is that currently only one patient at a time can be treated and it takes time to switch the proton beam between rooms. Achieving efficient throughput and avoiding patients waiting too long for the treatment beam is dependent on several

A UNIQUE OPPORTUNITY FOR CONSISTENT PROTON TREATMENTS

factors. First, not running too many rooms off one accelerator. Second, on the equipment being able to deliver a high dose rate so that individual fields can be treated in a short time and, finally, on being able to switch the beam between rooms quickly.

Treatment rooms will generally be a mix of fixed beam rooms where the beam can be directed at the patient only from one or two directions, and gantry rooms where the beam can be rotated around the treatment couch. Gantries for proton radiotherapy need to incorporate large and powerful magnets to bend the high energy protons. The resulting gantry structure can be three stories high, taking up the floors below and above the treatment floor level. These major pieces of engineering increase the initial cost, leading centres to treat with fixed beams where possible. For simpler treatments, a fixed beam, in combination with a robotic couch, can be used to deliver proton radiotherapy.

A good example is prostate treatment, where two lateral beams can be delivered by a fixed beam. A variant on the fixed beam is the dual inclined beam, where two beams at different angles can provide greater flexibility.

In some centres more complex plans may contain beams that can be delivered by fixed beams and beams that can only be delivered by gantries. In this situation the patient will receive treatment in different treatment rooms on alternate days with not all beams treated daily. This is possible with proton treatments as each field can deliver a uniform dose to the whole tumour.

PASSIVE SCATTERING VERSUS SCANNING TECHNOLOGIES

Nearly all of the treatments that have been delivered so far use a scattered proton beam to treat the patient. Passive scattering uses a range shifter wheel, or ridge filter, to modulate the energy of a narrow beam to create the spread out Bragg peak (SOBP) to produce a high dose to the target from a single beam direction. The narrow proton beam is scattered to produce a broad beam that can be used to target the complete treatment field in a similar fashion to a photon beam (Figure 2). The scattered beam then uses a custom collimator to define the field size and a compensator to alter depth of penetration across the beam aperture.

The compensator and collimator used for passive scattered proton radiotherapy are made individually for each patient and are unique for each treatment beam used in the proton treatment plan (Figure 3). Each collimator/compensator pair for every treatment beam needs to be manually inserted into the treatment nozzle prior to the irradiation of the patient. Although an effective solution, this can lead to manual handling and radiation protection issues for staff at the proton radiotherapy centre, as well as increasing the cost of proton treatments.

Figure 2. A passive scattering treatment system.

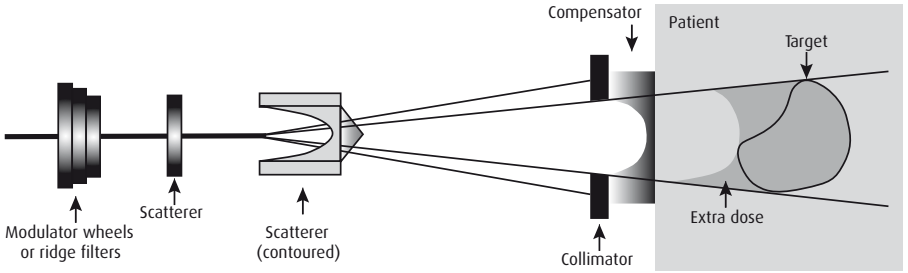
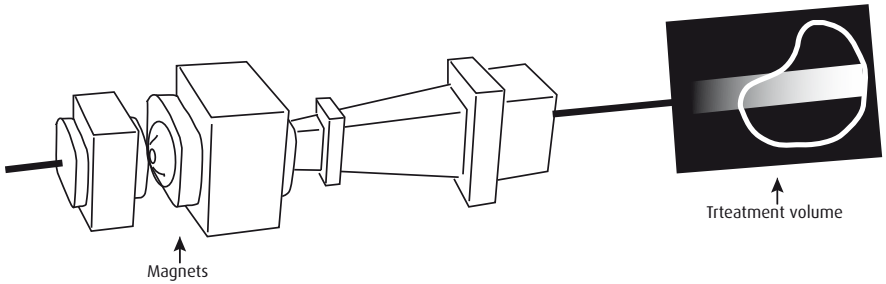


Figure 3. Individual collimator and compensator used in passive scattering proton systems.

Figure 4. A scanning proton treatment system.



PROTON RADIOTHERAPY PROVIDES DISTINCT DOSIMETRIC ADVANTAGES

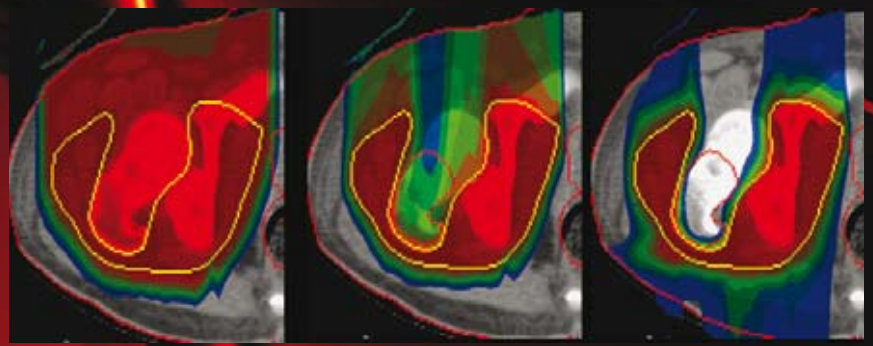


Figure 5. Conformity achievable from passive scattering, single field uniform dose and intensity modulated proton therapy (courtesy of Dr T Lomax).

Proton scanning systems are seen as the next generation of commercial proton technology. Scanning was first implemented at the Paul Scherrer Institute in Villigen, Switzerland. Firstly, we should consider why scanning beams are seen as being so important to proton radiotherapy. Scanning has the potential to both simplify and improve proton radiotherapy treatments. It has several advantages over passive scattering technology:

- It has the potential to reduce commissioning times.
- It does not require the manufacture of compensators or collimators for individual patients' treatment beams.
- It allows the delivery of more conformal treatments.
- It has the potential to increase patient throughput.

Scanning technology does not require the custom collimator or compensator because the beam can be controlled to irradiate the desired treatment positions by changing the position in the XY plane using magnets, and Z (depth) by adjusting the incident proton energy (Figure 4). Scanning reduces the cost of producing these customised devices. It also can increase throughput because less radiographer intervention is needed to insert a patient specific collimator and compensator combination for every treatment field.

Apart from avoiding patient specific compensators and collimators, scanning opens up the possibility of intensity modulated proton therapy (IMPT). The Paul Scherrer Institute has defined two main treatment modes of scanning treatments: First, single field uniform dose (SFUD), where each field delivers a homogeneous field across the volume. And second, IMPT, where the Bragg peaks from all fields are optimised such that each treatment beam provides a non-uniform dose delivery but, when combined, all treatment beams produce a uniform dose distribution. Both of these modes allow increased conformity with respect to passive scattering.

Figure 5 shows an example from where a volume has been planned using passive scattering, SFUD and IMPT. In passive scattering, the modulation width of the SOBP is constant and equal to the maximum width of the target along the beam axis, which results in an under spill of dose for most volumes. Both SFUD and IMPT avoid this problem and can achieve increasing degrees of conformity.

It has also been postulated that scanning reduces the time for commissioning and planning. Passive scattering technology certainly has many treatment options that take a long time to commission and many centres do not commission all options. In theory, one would have to commission only one scanning option but, in practice, data on commissioning a commercial scanning system are scarce.

THE CURRENT SITUATION IN THE UNITED KINGDOM (UK)

Proton radiotherapy is currently available to UK patients via a specialised commissioning service of the NHS, http://www.specialisedservices.nhs.uk/service/proton-beam-

therapy. An expert reference panel receives patient referrals for treatment abroad at one of three centres: the Paul Scherrer Institute, Villigen, Switzerland; the Centre-Protontherapie, Orsay, France; or the University of Florida Proton Therapy Institute, Jacksonville, USA. This national service has been available since April 2008 and has resulted in more than 70 UK patients being treated overseas. Although providing a necessary and important clinical service, treatment abroad for several weeks can provide significant challenges for patients and their carers.

There is a clear emphasis on the treatment of paediatric patients in the current list of approved diagnoses, with an expected patient benefit from the reduction in the integral dose delivered for this group. The UK population receiving proton radiotherapy therefore has a significantly different profile from the international standard, with approximately a quarter of patients receiving proton radiotherapy presenting with prostate cancer[2]. In the USA, prostate cancer patients are the predominant referral for proton radiotherapy.

The treatment of patients abroad provides a service only for those who will benefit most from this form of treatment. However, in its current form, the number of patients receiving this form of radiotherapy is unlikely to meet fully the UK demand. An early estimate of the number of patients that could benefit from proton radiotherapy in England alone is in excess of 1700 cases per annum[3]. Treating this number of patients at facilities overseas would be a significant logistical challenge associated with substantial costs. It is therefore highly likely that UK based proton radiotherapy facilities will be required in the next five years.

CLINICAL AND COST-EFFECTIVENESS OF PROTON RADIOTHERAPY

Opponents of proton radiotherapy often point to a lack of clinical evidence and the high relative cost of the treatment facilities to question the need for proton radiotherapy in the UK. Systematic reviews are unlikely to provide any definite answers on the effectiveness of proton radiotherapy for a number of reasons: The lack of good quality randomised trials; the lack of comparative studies in general; the use of different definitions of acute and late effects of treatment; and the emphasis on single institution reported series of proton only treatments. What is clear is that proton radiotherapy provides distinct dosimetric advantages over photon treatments, including IMRT, in terms of reduced dose to normal tissues, particularly distant to the tumour[4]. This reduction in normal tissue dose may provide the potential for dose escalation, or morbidity reduction for patients receiving proton radiotherapy.

Ultimately, the clinical effectiveness of proton treatment must be demonstrated by clinical trials. However, one difficulty in this approach is that the main difference between proton and photon radiotherapy dose distributions lies in the low to medium radiation dose range delivered to the patient, with protons affecting smaller volumes of healthy tissues in this range. This difference is likely to be demonstrated clinically in the late effects of radiotherapy treatment, whose frequency can be difficult to measure and requires lengthy follow-up of the patients. The length of follow-up negates the ability of clinical trials to guide health policy in the short term.

As discussed by Zeitman et al[5], even those opposed to proton radiotherapy in general, accept that their application to paediatric tumours is desirable, if not clinically proven, and should be supported without further proof. This is due to the fact that normal tissues in a growing child are particularly radiosensitive and the morbidity from conventional radiotherapy treatments can be substantial. The demonstrated improvements in the dose distribution by proton radiotherapy are highly likely to be advantageous for this patient group. Given the high cost of proton radiotherapy, it should perhaps be reserved for patients in whom great benefits over best quality photon radiotherapy are to be expected.

DRIVERS FOR TECHNOLOGICAL CHANGE

One of the most important areas of progress for proton radiotherapy is the ongoing development of technology. It is well known that proton radiotherapy treats far fewer patients than photon based radiotherapy and that commercially, proton radiotherapy is a much smaller worldwide market. As a result, proton radiotherapy equipment is currently less mature. However, since proton radiotherapy moved from the realm of the particle physics laboratory to dedicated clinical facilities either attached or affiliated to hospitals, the uptake of proton radiotherapy has accelerated and, along with it, the interest in developing improved technology and integrated solutions. The result is that compared to photon based radiotherapy, proton radiotherapy technology will undergo major developmental changes over the next few years.

The major hindrance to the greater use of proton radiotherapy centres is the substantial

SIGNIFICANT INVESTMENT INSTAFF TRAINING IS REQUIRED

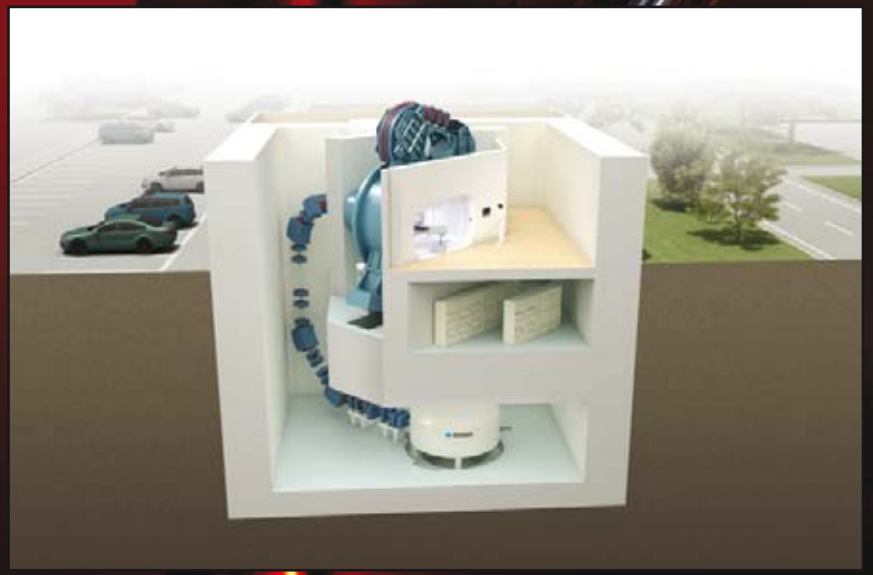


Figure 6. a) A new proton radiotherapy system designed in a vertical arrangement with a compact type rotating gantry and a 230MeV cyclotron (reproduced with permission from Sumitomo Heavy Industries).

b) A single room proton facility designed with a rotating cyclotron (reproduced with permission from Still River Systems).

size and cost of the cyclotron or synchrotron equipment necessary for patient treatments. Several companies are currently working on developments to reduce the size of clinical systems to deliver proton radiotherapy to patients. Figure 6 shows compact designs from two separate proton manufacturers.

CHALLENGES AND OPPORTUNITIES FOR THE UK

For a UK based proton radiotherapy centre to be operational, there will need to be a significant investment in staff training and education. The inclusion of proton radiotherapy in the educational syllabi for medical physicists, therapeutic radiographers and clinical oncologists, should be considered in the near future. This would provide the necessary background knowledge of the technologies and clinical applications to staff entering the profession over the next few years.

In addition, due to the high capital cost of the required equipment, and the relatively slow throughput of patients in proton radiotherapy centres, the standard hours of operation of hospital based proton centres is usually in excess of 10 hours a day, requiring multiple staff shifts and patient treatments potentially from 8am to 10pm. A UK proton service will therefore be required to provide an appropriate patient service for a routinely extended day, beyond the normal experience of radiotherapy departments. Servicing and medical physics support is also likely to take place outside of the extended working day, producing a major change in working practice for this staff group. These major changes for staff need to be considered in the context of providing an appropriate proton radiotherapy service for the benefit of patients in the UK.

In conclusion, there is a clinical need for proton radiotherapy in the UK although, ultimately, the clinical effectiveness of proton treatments should be demonstrated by clinical trials. The UK would be well placed to perform multi-institutional trials with close co-operation between UK institutions, with all proton treatments performed according to agreed protocols. Providing such evidence will lead to knowledge of the real proportion of patients for whom proton radiotherapy would be advantageous. It would also provide greater information about the cost effectiveness of proton radiotherapy, and allow for the future development of proton radiotherapy centres in the UK to be truly evidence based.

A UK national proton service, whether delivered within two or three treatment centres, provides a unique opportunity for consistent proton treatments according to nationally agreed protocols, with reliable and standardised long term follow-up of patients.

Carl Rowbottom leads the radiotherapy physics group at the Christie NHS Foundation Trust, Manchester. He is a fellow of the Institute of Physics in Engineering in Medicine and is the Institute's representative on the National Radiotherapy Implementation Group.

Adult

Base of Skull & Spinal Chordoma
Base of Skull Chondrosarcoma
Spinal & Paraspinal Bone and Soft Tissue Sarcomas (Non Ewing's)

Paediatric

Base of Skull & Spinal Chordoma
Base of Skull Chondrosarcoma
Spinal & Paraspinal 'adult type' Bone and Soft Tissue Sarcomas
Rhabdomyosarcoma
- Orbit
- Parameningeal & Head & Neck
- Pelvis

Ependymoma
Ewing's Sarcoma
Retinoblastoma
Pelvic Sarcoma
Optic Pathway and other selected Low Grade Glioma
Craniopharyngioma
Pineal Parenchymal Tumours (not Pineoblastoma)
Esthesioneuroblastoma

Table 1: List of approved diagnoses from the specialised commissioning service of the NHS.

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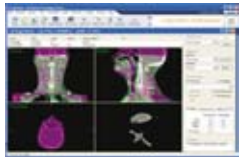

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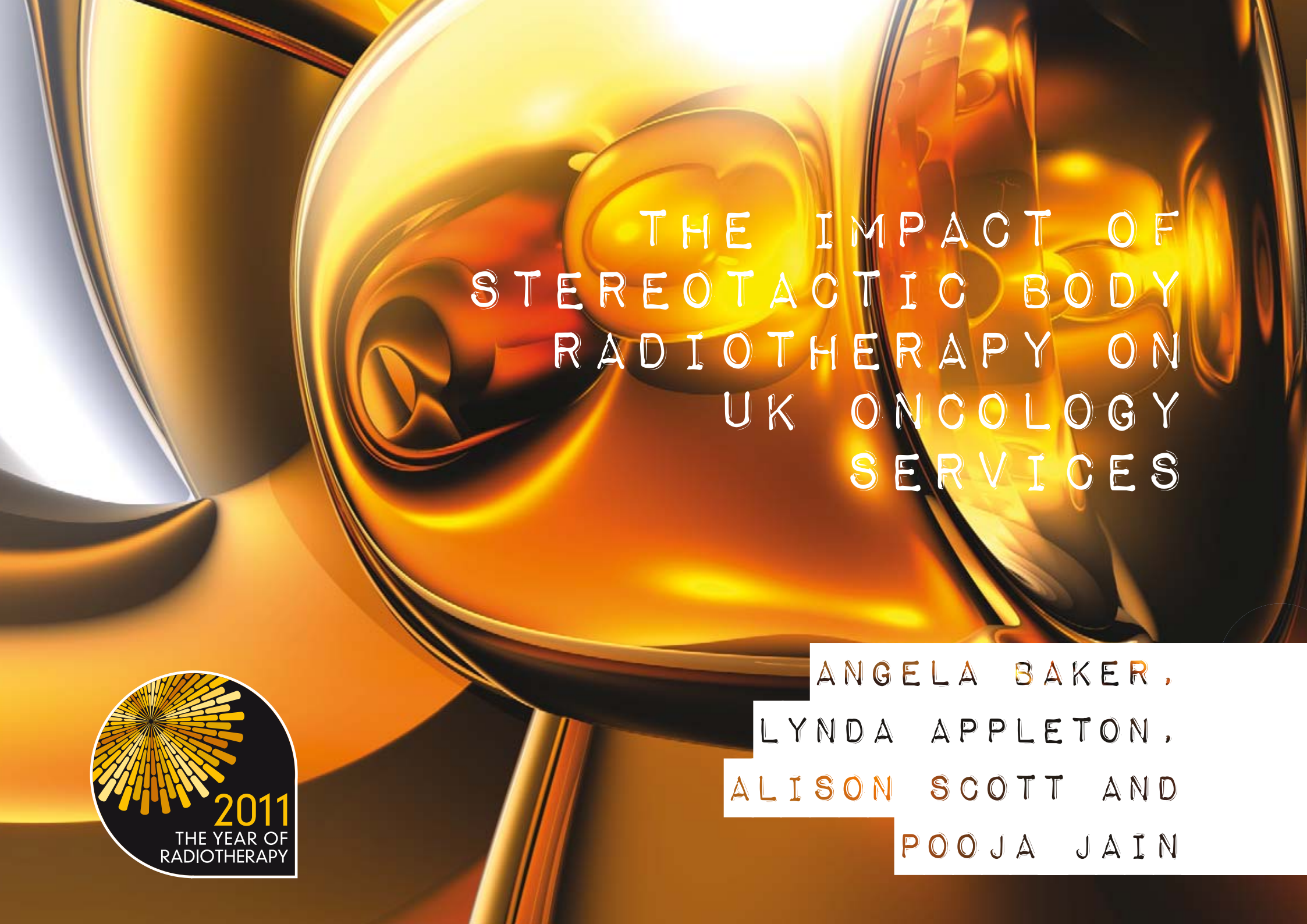


THE IMPACT OF STEREOTACTIC BODY RADIOTHERAPY ON UK ONCOLOGY SERVICES

ANGELA BAKER,
LYNDA APPLETON,
ALISON SCOTT AND
POOJA JAIN

2011
THE YEAR OF
RADIOTHERAPY

An overview of the current status of SBRT in the UK and the impact of this technique on future oncology services.

Stereotactic Body Radiotherapy (SBRT) was developed in the 1990s at the Karolinska Institute, Sweden and gained worldwide momentum after the phase I/II dose escalation studies by Timmerman[1]. The SBRT treatment technique is similar to that used for intracranial lesions, employing multiple radiation beams to target a tumour with high precision, delivering an ablative dose of radiation, made possible by limiting the treatment volume.

The radiobiological rationale for SBRT is that by delivering a few large fractions in a relatively short overall treatment time, a more potent biological effect is achieved1. Using high dose per fraction for extra-cranial lesions (especially in lung tumours) poses greater challenges due to tumour and organ at risk (OAR) motion both inter and intra-fractionally[2]. The advantage of this technique in lung cancer is that patients with early stage tumours, who are unfit for radical surgery, appear to have improved local control and disease specific survival than conventional radiotherapy[3-5]. The serious toxicity (≥ grade 3) reported in the literature is below 5 per cent[6].

It is important to consider that a number of the published studies were done prior to the era of on-line image guidance equipment. The introduction of image guidance techniques has the potential to enhance target localisation and the safety of SBRT treatments. With the increased availability of volumetric imaging on linacs, most centres are now delivering extra-cranial stereotactic radiotherapy in a frameless context, enabling a greater flexibility in the types of patients who can benefit from SBRT.

The implementation of SBRT is a multidisciplinary team effort and needs a clearly defined pathway. The practice of SBRT requires a high level of confidence in the accuracy of the entire treatment delivery process due to the delivery of large doses in a few fractions, and the minimisation of normal tissue toxicity with rapid dose fall off away from the target.

The UK SBRT Consortium was founded in 2008 to ensure safe, consistent implementation of this technique, for lung cancer patients initially, across the UK. Comprehensive guidelines which detail key publications, patient selection criteria, quality assurance recommendations, planning guidelines and dose/fractionation schedules have been issued. The Consortium has played a vital role in ensuring implementation is achieved safely without the infrastructure provided by a clinical trial process. The model used for lung SBRT treatments will be extended to other sites as experience is gained.

CURRENT STATUS

In June 2010 a questionnaire was circulated by the SBRT consortium to identify the current status of SBRT in the UK and to provide a baseline against which future activity could be measured. Analysis of the questionnaire data was also distributed to the National Radiotherapy Implementation Group SBRT short life working group.

Questions covered tumour sites, patient numbers, equipment utilised, resource implications and quality assurance. At this point there were seven treating centres with a further six centres intending to treat using this technique in the near future.

Lung was the most common tumour site, followed by liver, spine, prostate, pancreas and paediatric tumours (figure 1).

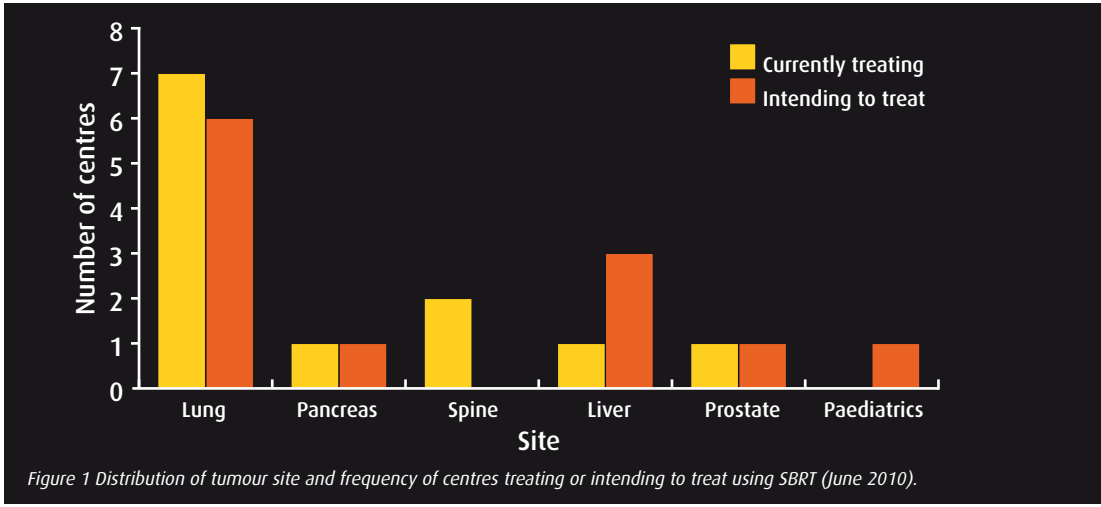


Figure 1 Distribution of tumour site and frequency of centres treating or intending to treat using SBRT (June 2010).

There was a spread of treatment equipment across all manufacturers: Cyberknife, Varian OBI, Elekta XVI and Tomotherapy. The Cyberknife centres, as expected for a product marketed as a radiosurgery system, were treating larger numbers of patients per annum from more anatomical sites.

QUALITY ASSURANCE AND COMMISSIONING GUIDELINES

A recent report from the American Association of Physicists in Medicine (AAPM) task group 101[7] states that:

In SBRT, confidence in the accuracy of the technique requires an integration of the modern imaging, simulation, treatment planning and delivery technologies in all phases of the treatment process.

This has been addressed by the consortium in the production of guidelines detailing

each of these areas.
The Quality Assurance (QA) subgroup has written recommendations on the commissioning of SBRT which details:

- Dosimetry requirements
- Immobilisation methods
- Assessment of tumour motion methods
- Treatment planning techniques
- Types of algorithms which should be used
- Linac QA
- Image guidance
- Plan delivery techniques

All of these areas are also covered in the AAPM task report[7].

The lack of funding for a nationwide QA programme is a significant issue and the consortium is currently exploring avenues where a QA programme could be established, outside a trial setting.

It is recommended that each centre should measure the systematic and random errors relating to their own systems of immobilisation and image guidance before using any new technique[8]. This should be undertaken before any new tumour site is treated using SBRT.

Traditionally, lung SBRT was delivered using fixed frames or vacuum immobilisation devices with diaphragmatic pressure to reduce breathing motion[4]. With the introduction of four-dimensional computed tomography planning and 3D volumetric image guidance on linear accelerators, it is now possible to deliver SBRT without rigid frames with greater accuracy[9].

Locally we have evaluated our standard lung immobilisation equipment using cone beam CT data from our Varian OBI linacs and have quantified the pre and post treatment uncertainties. The post treatment systematic $\sum$ and random σ errors were less than 2mm in all directions (table 1) representing the residual displacement error, plus the intrafraction patient movement. These are the important values as we use an on-line imaging protocol with an action level of 2mm, and support the GTV to PTV (gross tumour volume to planning treatment volume) margins of 5mm. This gives confidence in the immobilisation equipment and the treatment accuracy.

Similar results have been shown by a number of UK centres using standard immobilisation; and they are equivalent to values reported by centres using vacuum bag or frame devices.

PHYSICS (PLANNING) ISSUES

Although the field sizes used are smaller than for conventional lung radiotherapy, they are not generally small enough to prove a challenge for most modern treatment planning systems (unlike SRS in the cranial setting). However, the combination of relatively small

	Pre-treatment CBCT (mm)			Post-treatment CBCT (mm)		
Set-up error	VERT	LONG	LAT	VERT	LONG	LAT
Mean	-0.2	-0.9	-0.4	0.8	0.2	0.5
SD	2.7	3	3	1.4	1.1	1.4
$\sum$ setup	1.8	4.1	3.3	0.9	0.6	0.9
σ setup	3.0	3.3	3.2	1.7	1.3	1.8

Table 1 Pre- and post-treatment systematic and random error margins (in mm)

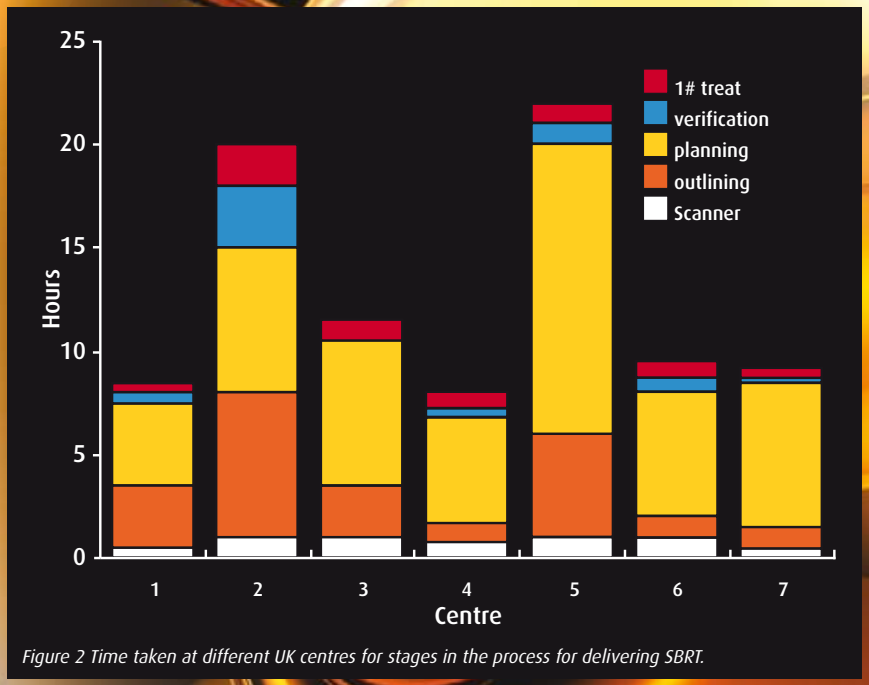


Figure 2 Time taken at different UK centres for stages in the process for delivering SBRT.

Schedule	In-room time (min)	No. of hospital visits	Total time (min)
SBRT (5 x 11 Gy)	24	5	120
SBRT (3 x 18 Gy)	24	3	72
Standard (20 x 2.75 Gy)	12	20	240

Table 2 Summary of in-room time and hospital visits for SBRT treatment and standard treatment.

fields (~4-6cm) and low density lung does introduce uncertainties in the dose distribution. Therefore using a type B algorithm (eg Anisotropic Analytical Algorithm, or collapsed cone), which accurately assesses lack of lateral scatter, is strongly recommended.

To keep OAR doses as low as possible, many beams are utilised (nine or more) and it may be advantageous to use a non-coplanar beam arrangement. The use of dynamic arc techniques will produce a more conformal dose distribution, whilst treating a larger volume of the lung to a low dose bath[10]. Before implementing such a technique, consideration must be given to the interplay effects between the moving target and the moving leaves[11].

RESOURCE IMPLICATIONS

Aside from the tumour, a number of key organs at risk need to be outlined, so that intended radiation dose to the latter can also be accurately ascertained. If available, help from radiology colleagues is invaluable but this increases significantly the outlining time compared to standard treatments. The treatment planning must consider the multiple OARs and the effect of reduced lateral scatter in the lung surrounding a small tumour. As such, it is relatively complex. At Clatterbridge Centre for Oncology (CCO) it is performed by physicists only.

Figure 2 shows a breakdown of the components of the process from seven UK SBRT centres.

In-room timings showed this SBRT technique to be an efficient use of linac time. It also gives the additional advantage of a reduced number of hospital visits for the patient. This is shown in table 2 using data from Clatterbridge Centre for Oncology.

As experience increases, there is a decrease in the time for each step in the process, especially the planning stage, and this is similar to the reductions seen when intensity modulated radiotherapy (IMRT) planning techniques were first implemented. It is expected that when any new site is treated with SBRT, these values may increase during the initial implementation phase.

In-room times are reduced with the use of automatic couch corrections from the treatment consoles. An increased use of rotational techniques such a Volumetric Modulated Arc Therapy and RapidArc will also reduce the treatment time - current nine static field technique 12 min beam on time, if two arcs are used, this could be reduced to two minutes.

DATA COLLECTION

When introducing a new technique to your centre, even if the use of the technique has been proven in the literature, we appreciate that it is good practice to collect toxicity and outcome data. This data collection needs to be prospective rather than retrospective. However, the NHS does not provide the funding to support this.

This has been addressed locally by involving the clinical effectiveness team to produce a database of treatment toxicities but this is based on the small number of SBRT patients currently being treated. Quality of life data are being collected by nurse specialists. There will be additional follow up clinic visits and appropriate diagnostic imaging dependent on the treatment site where this technique is used.

The UK Consortium means to facilitate consistent data collection across the country and aims to establish a national database of SBRT toxicities and outcomes.

QUALITY OF LIFE

Reduced treatment visits as a consequence of SBRT may impact positively on the daily life of individual patients. However, the treatment planning and delivery process is prolonged. It is important to manage patient and carer expectations, stressing that they have early disease and the necessary time and care is essential to deliver the best possible treatment.

SBRT appears to be associated with minimal acute and late toxicity. Fatigue is one of the most commonly reported symptoms. The relatively good tolerability of SBRT may result in improved quality of life outcomes which should be formally evaluated.

WORKFORCE DEVELOPMENT

Due to the high technical demands of SBRT, the American Society for Radiation Oncology and the American College of Radiology have jointly published practice guidelines that detail recommendations for staffing levels and staff responsibilities for this technique[12].

Currently at CCO, the SBRT clinician will be present at each treatment fraction to approve the soft tissue match on the CBCT and any necessary isocentre corrections. However, we are working towards the SBRT treatment being a radiographer/physicist led Image Guided Radiotherapy process. The SBRT clinician would be available at the verification (day 0) appointment and then would hand over to the SBRT radiographer/physicist team for subsequent treatments. This team would provide expert knowledge of the treatment plan (physicist) and the image guidance method (radiographer) and could therefore make the appropriate decision for required isocentre corrections.

This is a logical progression following the recent increase in use of soft tissue registration as routine practice in the UK, especially for lung cancer patients. The experience gained for routine conformal treatments will lead to a safe delegation of responsibility to competent radiographers. We are working with academic institutions to produce Masters level modules in advanced imaging techniques, which will incorporate a competency assessment for SBRT treatments image evaluation.

The next step would be the establishment of consultant radiographer posts specialising in SBRT with the technical expertise to take responsibility for soft-tissue match during treatment and to co-ordinate the SBRT radiographer team of advanced imaging practitioners required for this technique. They would have their own workload of SBRT patients to provide on-treatment review and follow-up clinics and would assist in the

SPECIALISED TEAMS MUST BE ESTABLISHED WITH CREATION OF CONSULTANT RADIOGRAPHER ROLES

development of national SBRT guidelines, training and research projects.

SERVICE DEVELOPMENT

One of the barriers to implementation of SBRT is the lack of an appropriate tariff to recognise the extra planning effort required for this technique. How do we convince commissioners to ensure correct payment? Tariffs are based usually on number of treatment fractions rather than complexity of the planning and treatment process. The use of image guidance, for example, is not currently recognised within the tariff system. This issue has also been highlighted in the UK provision of inverse planned IMRT treatments[13]. Mayles discusses the need for financial recognition of the additional planning effort required for IMRT, an argument equally applicable to SBRT treatments. Unless a compensating increase in payment for the treatment preparation and data collection methods is implemented, it is unlikely that the desired level of SBRT provision will be achieved in the UK.

At a recent 'Britain Against Cancer' conference, the Health Secretary, Andrew Lansley, outlined plans to develop a range of tariffs to reward high-quality, cost-effective services[14]. These may help to encourage innovation and the early adoption of new techniques, such as SBRT.

The NRIG short term SBRT working party report (due early 2011) will provide guidance for commissioners, providers and clinicians for the provision of SBRT for all anatomical sites. It is anticipated the report will assist in solving this problem and enable more centres to offer this technique.

SBRT RESEARCH IN THE UK

There is a vast number of published papers on SBRT, however there is a lack of level 1 evidence, with a striking absence of multicentre randomised controlled trials. Most of the literature on SBRT consists of cohort studies, phase I and a few phase II studies [15]. Radiobiology predicts that a high biological equivalent dose (≥100Gy) is needed for good local control (>80%)[16]. Published outcomes from SBRT also support this, with dose/fractionation regimen delivering less than 100Gy being associated with poor local control[17]. This observation makes it difficult to randomise patients between the standard UK regimen of 55Gy/20 fraction (BED of 70Gy) against SBRT dose fractionation with a biologically equivalent dose higher than 100Gy. A couple of international phase III trials began in 2008, but are slow to recruit.

This does not mean that there is no place for research in SBRT. On the contrary, there are many unknowns. Even though local control rates are equivalent to surgery, this does not translate into a survival advantage. This phenomenon may be explained by the fact that patients selected for SBRT (over surgery) often have significant comorbidities, which may also affect their overall survival. Relapse patterns following SBRT differ significantly from conventional radiotherapy; with delivery of ablative doses, patients appear to relapse at distant sites with further treatment options limited, given that patients are usually medically inoperable. Both these factors could be responsible for the lack of survival advantage despite good local control.

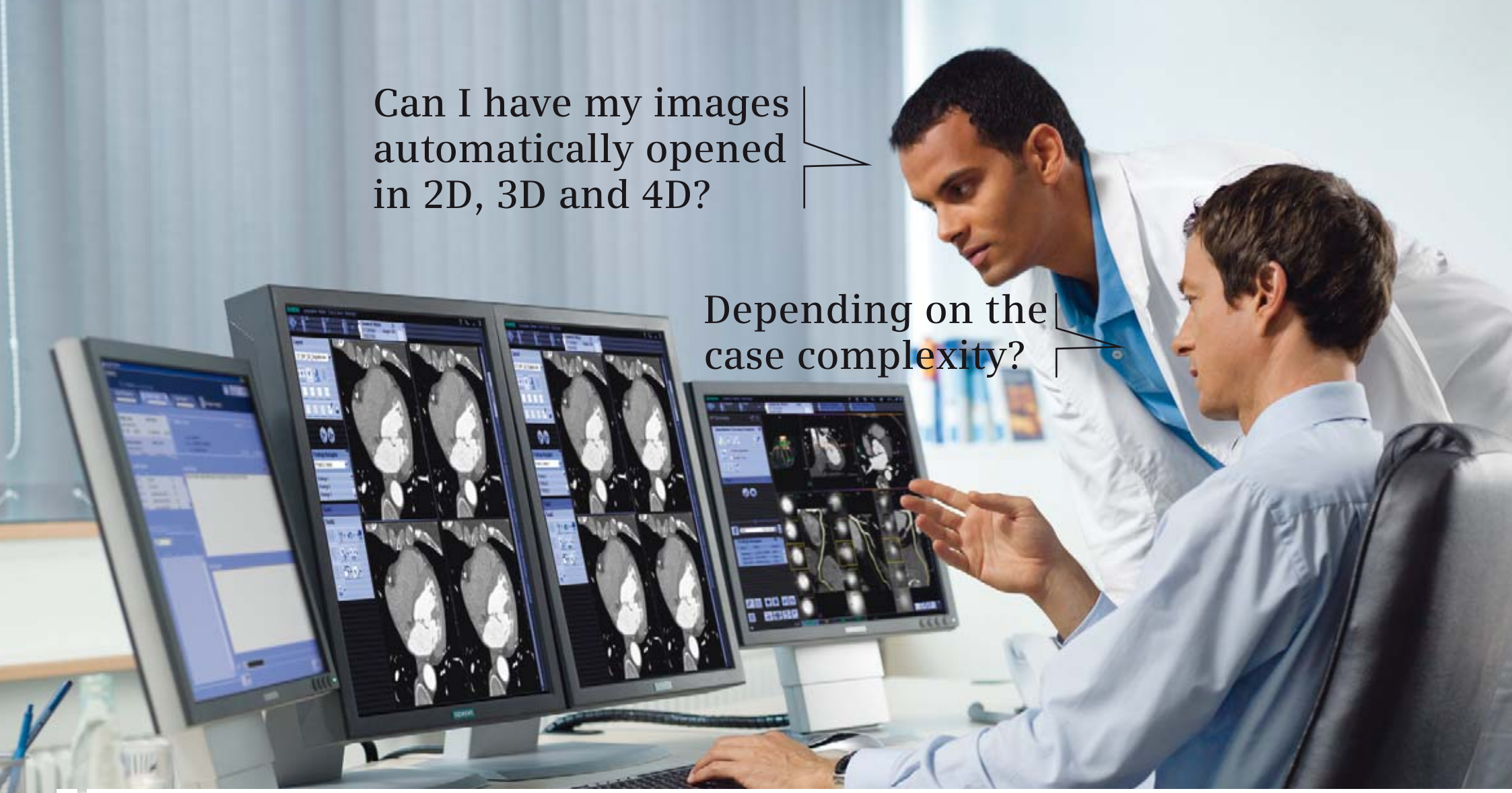
Due to these factors, it is crucial that research in SBRT moves away from the medically inoperable. Certainly there are trials in Europe and America comparing SBRT to surgery, but due to the vastly differing trial arms they are slow to recruit[18]. The UK Consortium is also planning a trial of SBRT against surgery. A multicentre UK trial will help budding UK centres to start SBRT. In addition, the quality assurance associated with the trial will ensure best practice across centres delivering SBRT.

FUTURE IMPACT

There is an increased body of evidence for the use of SBRT for oligometastases, liver, paraspinal, pancreas, prostate and kidney tumours[2]. Some of these sites are already being treated with SBRT in the UK. Each will have different issues to consider in terms of immobilisation, planning technique and image guidance. Further training may be required to evaluate the image guided images as the new sites may not be currently treated using radiotherapy and soft tissue matching.

As all new linacs are recommended to be capable of delivering image guided 4D adaptive radiotherapy[19], this gives the potential for an increased number of SBRT treatments.

The number of stereotactic systems available in the UK with the facility for tumour tracking is expanding. The Cyberknife system provides continuous image guidance, target tracking and real time corrections. The Novalis Tx system provides marker based tumour tracking with gating techniques.



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This ability to accurately track tumours during respiratory motion solves one of the main challenges of utilising SBRT for lung and abdominal tumours.

New equipment currently being developed provides real time imaging, together with increased flexibility for beam arrangement. This is called the Vero system, which has a gimbals-based mechanism designed to anticipate tumour mobility during treatment.

There is an obvious need for specialisation of staff due to the complex nature of the technique. Each department should establish a stereotactic team, dedicated to stereotactic treatments and associated issues. This would include clinicians, physicists and radiographers and may be appropriate for both extra-cranial and cranial sterotactic treatments. There may also be a requirement for a SRT dedicated linac in each department. This is already happening in the UK with Cyberknife equipment at a number of centres.

A current informal referral system enables patients to have SBRT treatment if thought to be beneficial (even if not offered in their local centre). This might usefully be developed into a centralised national referral system to SBRT centres across the UK, considering the specialisation in different anatomical sites of each hospital.

CONCLUSION

Teamwork, national integration and collaboration are fundamental for the implementation of the complex, continuously evolving technique of SBRT.

The provision of SBRT must be a patient focused service with a clear vision to offer all patients the most appropriate treatment for them. This should be equitable across the UK.

SBRT for small NSCLC (non-small cell lung cancer) tumours is increasing local control rate and significantly improving the patient's quality of life. It seems likely that similar advantages are possible for other tumour sites and therefore we expect a growth in hypofractionated techniques in the UK.

Arguably, if the UK radiotherapy workforce is to be able to meet this challenge, two areas require urgent development: Firstly, additional funding must be provided to support implementation of new technologies, both in terms of quality assurance and data collection. Secondly, specialised teams must be established with the creation of consultant radiographer roles specifically in this area.

Angela Baker is the lead research and SBRT radiographer. Lynda Appleton is a research nurse. Dr Alison Scott is the lead stereotactic physicist. Dr Pooja Jain is a consultant oncologist with special interest in technical radiotherapy for lung cancer. All practice at the Clatterbridge Centre for Oncology. CCO was one of the first UK centres to implement SBRT in lung patients and was a founding member of the UK SBRT consortium.

Acknowledgements

We would like to thank the UK SBRT consortium members for their input to this article.

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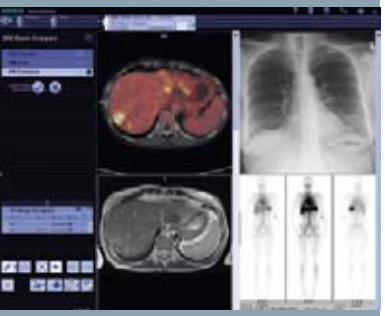
Innovative integration



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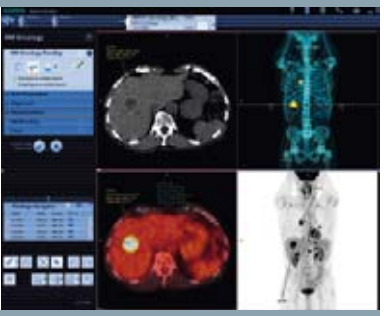

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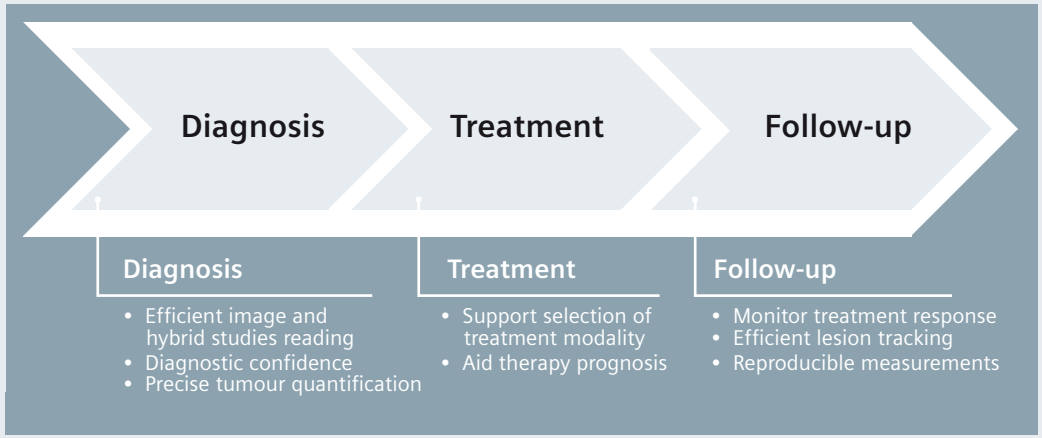

Delivered functionality is dependent on the purchased configuration

CYBERKNIFE TECHNOLOGY AND ITS FUTURE CONTRIBUTION TO ONCOLOGY

ALEXANDRA AITKEN, NIHAL SHAH,
PETE OSTLER AND PETER HOSKIN

CyberKnife has been hailed by the media as the 'must have' radiotherapy technology. But what are its true capabilities?

INTRODUCTION

Intracranial stereotactic 'radiosurgery' was developed in 1951 by a Swedish neurosurgeon, Lars Leksell[1]. The term 'radiosurgery' was initially defined as the delivery of an extremely high radiation dose to an often critically located small intracranial lesion during a single session. In order to minimise dose to normal tissues, multiple non-coplanar beams entering the patient at different locations were used to deliver the high target dose.

Since 1951, radiosurgery has undergone significant technical and clinical developments and, in more recent years, stereotactic radiotherapy has been investigated, developed and extended to extra cranial treatment sites with the intent to deliver a very high dose over a small number of fractions in order to have an ablative effect on the tumour[2]. When delivered over several sessions, it is commonly referred to as fractionated stereotactic radiotherapy (SRT) and is currently used to treat both benign and malignant tumours.

Most stereotactic platforms available currently consist of a dedicated stereotactic delivery system and an image guidance system - an essential requirement for SRT delivery. Existing radiosurgery systems include CyberKnife, Gammaknife and Tomotherapy. In addition, several linear accelerators are now equipped with stereotactic beam collimators and head frames.

One such system is the Novalis Tx radiosurgery platform. This system consists of a Varian Trilogy linear accelerator (Varian Medial Systems, Palo Alto, California, USA) with a micro multi leaf collimator in conjunction with the ExacTrac (Brainlab, Munich, Germany) image guidance system, offering real time imaging and corrections in six degrees of freedom. The Elekta Axesse (Elekta, Stockholm, Sweden) also offers a similar integrated stereotactic system.

The Gammaknife (Elekta, Stockholm, Sweden) is a well established radiosurgery system for intra-cranial work requiring a fixed head frame for treatment delivery purposes, whilst the Tomotherapy Hi-Art system (Tomotherapy, Madison, USA) utilises a ring gantry and delivers helical intensity modulated radiotherapy (IMRT) by means of thousands of small beamlets. This system utilises on-board image guidance with megavoltage computed tomography. The CyberKnife system (Accuray, Sunnyvale, California, USA) is an image guided robotic radiosurgery system featuring a robotic couch with six degrees of freedom and continual real-time kV image guidance (see figure 1). The robotic arm on which the linear accelerator is mounted enables the delivery of non-isocentric and non coplanar treatment beams with a high degree of precision. It is suitable for lesions anywhere in the body including structures that move with respiration.

CYBERKNIFE

The CyberKnife system has been under technical development for almost 20 years, whilst the basic concept has remained unchanged. However, significant improvements and additions were implemented more recently. CyberKnife is routinely used to treat brain,[3,4] head and neck,[5,6] spine,[7,8] lung,[9,10] liver,[11] pancreas and prostate[12,13] tumours, in addition to nodal or other tumour recurrences.

The treatment delivery system for the CyberKnife includes an X-band cavity magnetron, a standing wave and side-coupled waveguide, which produces 6MV x-ray beams at a dose rate of 1000cGy/min[14]. Bending magnets and beam flattening filters are not required and secondary collimation is provided by either fixed circular collimators ranging in size from 0.5mm-60mm, or a variable aperture collimator, which enables the same selection of collimator sizes without a physical change of collimator. Small collimator fields can be complex to calibrate due to steep dose gradients and electronic disequilibrium.

The robotic arm or manipulator, (Kuka Roboter, Augsburg, Germany) on which the linear accelerator is mounted, has the ability to move in six degrees of freedom and moves around the patient with a high degree of precision providing sub-millimetre position reproducibility. The increased geometric flexibility does, however, require more extensive primary barriers than those needed for conventional gantry mounted linear accelerators[14].

Treatment planning

As with all current radiotherapy systems, a 3D CT dataset is required for planning purposes, from which a 3D patient model is generated. Treatment beams are defined by

IT MAY BECOME THE TREATMENT OF CHOICE FOR PROSTATE CANCER

Figure 1. CyberKnife robotic delivery system

a vector linking a direction point, found usually within the target volume, and a source point, which correlates with the position of the linear accelerator's focal point. Each source point forms a 'node' with a set of 'nodes' forming a path set. Path sets provide non-coplanar beam directions and can be achieved without repositioning the patient.

Treatment delivery

Prior to and during treatment delivery, the digitally reconstructed radiographs (DRRs) generated from the 3D CT are automatically registered to the live images acquired using the X-ray imaging system, which determines the beam alignment. Internal radiographic reference points based on bony anatomy or implanted fiducial markers, in or around the tumour, are required for target localisation.

Before each fraction is delivered, the patient can be positioned using the adjustable treatment couch; this reduces the corrections required from the robotic manipulator. Any additional translational or rotational adjustments during treatment, identified from the real-time imaging, are relayed to the robotic manipulator and corrected, ie the alignment adjustments required are applied by correcting the beam position and orientation relative to the patient.

The unique tracking system featured on CyberKnife enables compensation for all small translations and rotations obtained from the latest image acquired. With the real time image guidance system and alignment correction, a very high dose conformality and steep dose gradient can be achieved. The ability to deliver non-isocentric and non-coplanar beams without repositioning the patient provides additional benefit.

Respiratory motion tracking

A respiratory tracking system (Synchrony, Accuray, Sunnyvale, California, USA) is used for treatment delivery to tumours that move with respiration. The beam moves during treatment ensuring continuous alignment of the beam with the moving target volume. The concept of this system is based on a correlation model between tumour position and external marker position. Prior to treatment delivery, the tumour position is determined by acquiring x-ray images at multiple time points and a correlation model is generated by relating the tumour position at different phases of the respiratory cycle to the simultaneous external marker position.

Throughout treatment delivery the position of the tumour is determined by the position of the external markers using the correlation model. Optical markers are used to provide the external signal. Separate correlation models are built for each marker with each model providing an estimate of target position. An average of all three estimates is then calculated resulting in a final position estimate. The model is continually updated throughout treatment, adapting to any changes in target position or motion accordingly. There is however no fixed or constant relationship between external contour and tumour position for extra cranial sites between fractions and during treatment delivery. Therefore the correlation model is regularly adjusted using the x-ray imaging data[14].

A HIGH DEGREE OF PRECISION IS ACHIEVED THROUGH SUB-MILLIMETRE POSITIONING

Fiducial Insertion

Fiducial markers are required for most extra cranial lesions when using the CyberKnife system. This enables the system to track the tumour in six degrees of freedom (ie all translations and rotations) throughout treatment delivery. A minimum of three fiducials are required for the system to accurately track the lesion, however it is recommended that four to six fiducials are inserted due to the uncertainties in localisation of the individual fiducials[15].

Fiducials should be 0.7 to 1.2mm in diameter and 3mm to 6mm in length. Several requirements need to be met when undertaking fiducial insertion. These include a minimum distance of 2.0cm between fiducials, a 15 degree angle between three fiducials, non-collinear placement and maximum distance of 5-6cm from the lesion. If these requirements are not met, some fiducials may not be suitable for tracking purposes and consequently tracking accuracy may be compromised. An additional tracking algorithm does enable lung tumours to be tracked without markers, provided the tumour diameter is greater than 15mm in all directions and positioned in the peripheral region of the lung.

The fiducial placement procedure is very similar to a CT guided biopsy with comparable complications and challenges[16]. Potential complications include the risk of pneumothorax, haemoptysis, haemorrhage and perforation of bowel, depending on the location and position of the tumour.

INTRA-CRANIAL STEREOTACTIC RADIOTHERAPY

Radiosurgery is an established form of treatment for both benign and malignant intra-cranial lesions and has shown good results with minimal side-effects. Surgical resection remains the gold standard for treatment and aggressive resection offers the best results. However, in many cases surgery may be contraindicated. Radiosurgery has been used as both a primary and adjuvant treatment modality following surgical excision. Whole brain radiation therapy and/or chemotherapy are used in many cases following surgical resection. As whole brain radiotherapy and chemotherapy have significant side-effects, stereotactic radiosurgery may be used as an alternative adjuvant treatment. Moreover, for inoperable patients, stereotactic radiosurgery is the only available ablative procedure targeted directly at the tumour, whilst sparing surrounding healthy tissue. Phase III randomised clinical trials comparing stereotactic radiotherapy alone with stereotactic radiotherapy, plus whole brain radiotherapy, had comparable overall survival rates[17]. However, local relapse was higher in patients treated with stereotactic radiotherapy alone. Neurologic preservation was similar between both groups.

EXTRA-CRANIAL STEREOTACTIC RADIOTHERAPY

Invasive immobilisation frames are used with many stereotactic systems. The CyberKnife system however, does not require the use of any invasive frames due to its unique ability to track throughout treatment. Similarly, alternative methods such as abdominal compression, are not required to assist in minimising motion.

LUNG

Stereotactic radiotherapy is not the primary treatment option for lung cancer and surgery remains the gold standard for early stage, non-small cell lung cancer NSCLC, providing excellent local control and survival outcomes[2]. However, radiotherapy is an alternative for patients who are poor surgical candidates, or who are inoperable due to the stage or the location of the tumour. Conventional radiotherapy has proved to be a poor alternative. Dose escalation is limited when using conventional external beam radiotherapy, mainly because large margins are applied routinely, which result in large treated volumes and increased side effects. Hence, results with external beam radiotherapy have been disappointing with long-term survival rates of just 15-30 per cent, and local failure in excess of 50 per cent in stage I NSCLC[18,19]. Complication rates are also high [20].

There is substantial published literature supporting the use of stereotactic radiotherapy (see table 1). Stereotactic lung radiotherapy allows the delivery of high dose radiotherapy, giving excellent local control, potentially resulting in improved overall survival compared to conventional radiotherapy[21]. SRT has been widely accepted for medically inoperable early stage NSCLC and has shown comparable outcomes to surgical series[22,23].

Delivered doses vary from 45-60Gy, usually given in three fractions. Tumour size is important when considering SRT because an increase in tumour size requires a higher dose, as large lesions have demonstrated local and distant failure[24].

Study	Number of patients	Dose	Median FU (months)	Local control	2 yr survival
Baumann et al, 2006 [33]	138	30-48 Gy in 2-4 #	33	85% (3 yr)	65%
Lagerwaard et al, 2008 [34]	206	3 x 20 Gy	12	97% (3yr)	65%
Nagata et al, 2005 [35]	45	4 x 12 Gy	30	98% (2 yr)	90% stage 1A 72% stage 1B
Onishi et al, 2007 [21]	257	18-75 Gy in 1-22 #	38	84%	70%
Timmerman et al, 2006 [36]	70	3 x 20 Gy 3 x 22 Gy	18	96% (2 yr)	55%
Xia et al, 2006 [37]	43	5 x 10 Gy	27	95% (3 yr)	78%

Table 1: Recent studies investigating outcomes from the use of SBRT

Delivery of stereotactic radiotherapy to lung tumours does, however, present a number of challenges. Primarily, the continuous respiratory induced motion has to be taken into account and the dose to normal healthy tissue needs to be limited. The ability to track the tumour with high accuracy using the CyberKnife system addresses these challenges and allows the use of smaller margins[25]. In contrast, gantry based imaging systems such as cone-beam CT may provide useful 3D or 4D information prior to treatment delivery, but are unable to account for target movements during treatment delivery, although the information can be used to design patient specific margins.

A drawback of the CyberKnife tracking system is that fiducials are required in many cases and they come with their own associated risks. Delivery also comes at the expense of longer treatment times (averaging approximately 90 minutes). Treatment times over 60 minutes could be associated with loss of biological equivalent dose (BED) of >10-15 per cent, which will impact on tumour control[26]. The number of beams should therefore be kept to a minimum when using CyberKnife, without compromising tumour coverage.

Numerous Radiation Therapy Oncology Group (RTOG) studies are currently investigating toxicity and efficacy of SBRT for early stage NSCLC. Additional studies investigating both inoperable and operable patients (RTOG 0236, RTOG 0618) and a phase III randomised multi-centre trial have been initiated in the Netherlands comparing surgery and SBRT in stage IA NSCLC[27]. Encouraging results have also been reported for lung metastases,[28] however further randomised trials using SBRT are required for both primary and oligometastatic lung disease.

Several trials using radiofrequency ablation (RFA) have reported clinical effectiveness in early stage inoperable NSCLC. As larger tumours or centrally located tumours are more likely to recur following either RFA or SRT, further studies are currently underway investigating the use of combined RFA and SRT to improve local control.

LIVER

Surgery is the treatment of choice for both primary liver tumours and limited liver metastases. However, for patients who are not suitable for surgery due to the extent of disease or medical condition, alternative strategies have been investigated. Conventional radiotherapy techniques can offer only palliation as the radiosensitivity of normal liver tissue limits the dose that can be delivered. SRT techniques enable ablative doses to be delivered to metastatic liver lesions, but long term published data with respect to outcomes are still lacking. SRT is generally used to treat primary liver lesions if other treatment modalities are not suitable, or in the event of recurrence.

RFA is now widely used for smaller lesions (<3cm) and has shown local control rates comparable to surgery[29]. RFA is, however, unsuitable for tumours situated close to the diaphragm, or large vessels and, in these cases, SRT would be the treatment of choice.

PROSTATE

Hypofractionated radiotherapy is emerging as an alternative treatment for early stage prostate cancer, potentially offering an increase in tumour control and patient survival compared to conventional radiotherapy[30]. Conventional radiotherapy is an accepted treatment option for a growing number of patients diagnosed with prostate cancer who are medically inoperable. However, the effectiveness is limited by the negative effects of the radiation on surrounding normal tissue.

The low alpha/beta ratio for prostate cancer suggests high dose hypofractionated radiotherapy will result in a favourable biological response. Data from the use of high dose rate (HDR) brachytherapy in prostate cancer support this theory and have shown positive results[31]. However, the HDR procedure is invasive, requires anaesthetic, the use of a catheter and hospitalisation. Stereotactic radiotherapy is the optimum external beam technique to deliver large doses per fraction, minimising the risks to surrounding normal tissue, and can offer a non-invasive alternative while applying the same dosimetric and biological considerations[32]. Furthermore, several recent published studies have demonstrated improved effectiveness and reduced toxicity with focused, high dose radiation treatments delivered in three to four treatment sessions with compensation for tumour motion, using stereotactic radiosurgery.

While improvements in treatment delivery techniques, such as Intensity modulated radiotherapy (IMRT), Intensity modulated arc therapy (IMAT) and SRT have enabled an increased dose per fraction to be delivered without increasing toxicity to normal tissue, and IGRT technologies including CBCT offer pre-treatment image guidance, these technologies do not address the issue of intrafractional motion. Due to the tracking ability that the CyberKnife system offers, target motion can be identified and corrections applied accordingly, ensuring accurate target coverage despite recurrent and unpredictable prostate motion.

Long term follow up data are still required to confirm effectiveness and late toxicities of stereotactic radiotherapy. If these data demonstrate that stereotactic radiotherapy is as effective as other modalities such as surgery, brachytherapy and cryotherapy, then stereotactic radiotherapy may become the treatment of choice for prostate cancer because it offers a non-invasive alternative with short treatment duration.

CONCLUSION

In the future, we are likely to see continued technological advancements and developments further improving the radiotherapy delivery systems that have contributed to the success of stereotactic radiotherapy. Conventional radiotherapy will continue to be suitable for many indications. However, effectiveness will always be limited by the negative effects of the radiation on the volume of surrounding normal tissue. In some circumstances, stereotactic radiotherapy may prove beneficial when used as a boost following radiotherapy.

The benefits offered by stereotactic radiotherapy include accuracy, potentially reduced incidence of treatment related toxicity due to its high conformity, and improved outcomes with dose escalation. It also offers a highly efficient treatment delivery in a small number of fractions. Patient selection is important and stereotactic radiotherapy is most suitable for smaller localised tumour volumes. Patients with distant active metastatic disease may not be appropriate, unless good local control is important for palliation.

Further studies are required in both the curative and palliative settings to investigate quality of life, symptom control, disease free interval, late effects and survival. Direct comparisons with alternative methods of treatment are also necessary to clarify the relative role of SRT in the overall management of malignant disease.

In conclusion, CyberKnife is a unique stereotactic platform and published data so far are encouraging with good local control being achieved in numerous tumour sites. However, large phase III studies are required if the true potential of stereotactic radiotherapy is to be established in both a palliative and curative setting.

Alexandra Aitken is principal radiographer, and Dr Nihal Shah, Dr Pete Ostler and Professor Peter Hoskin are consultant clinical oncologists at Mount Vernon Cancer Centre, Northwood, Middlesex, United Kingdom. Mount Vernon was the first National Health Service centre with CyberKnife.

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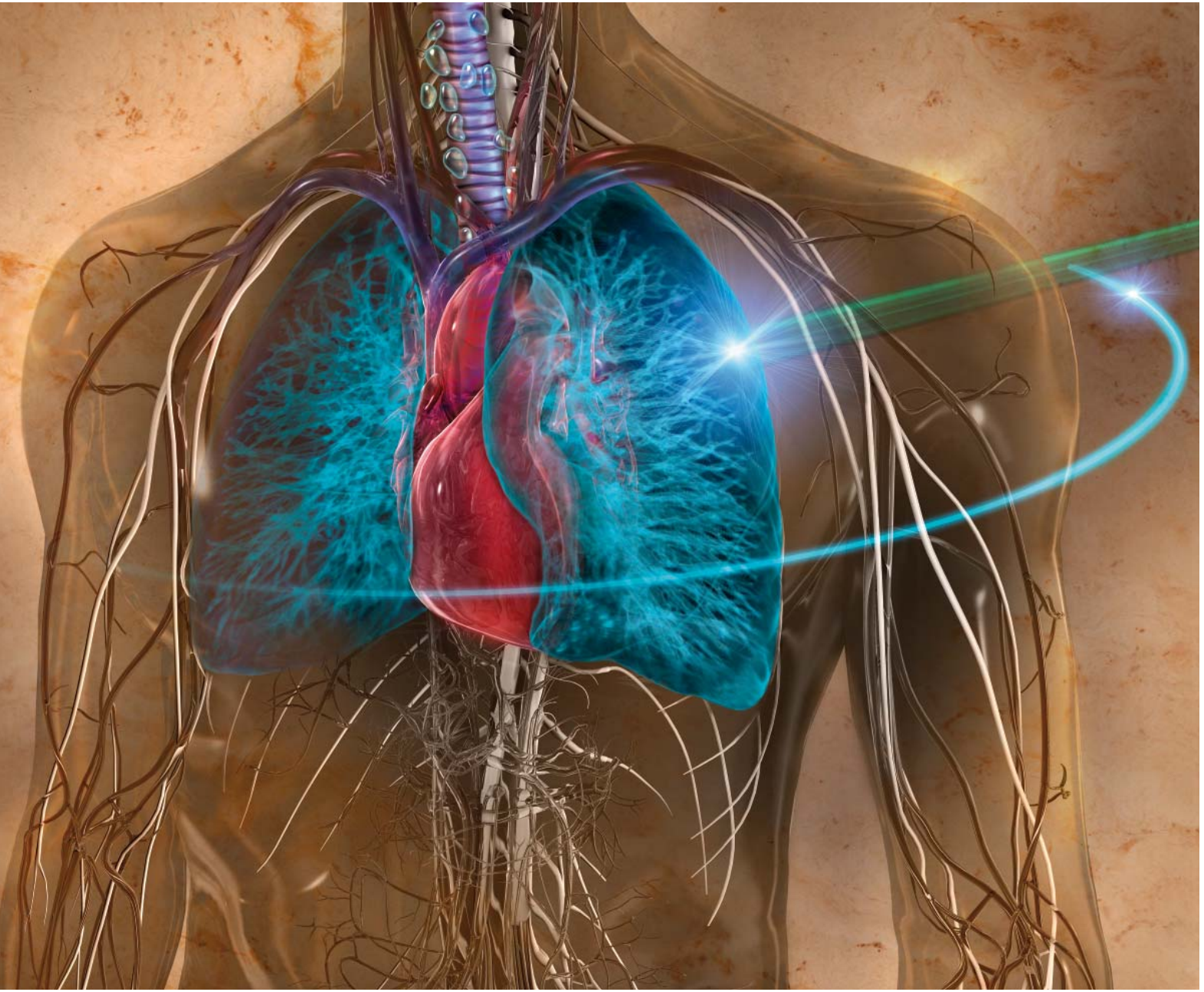

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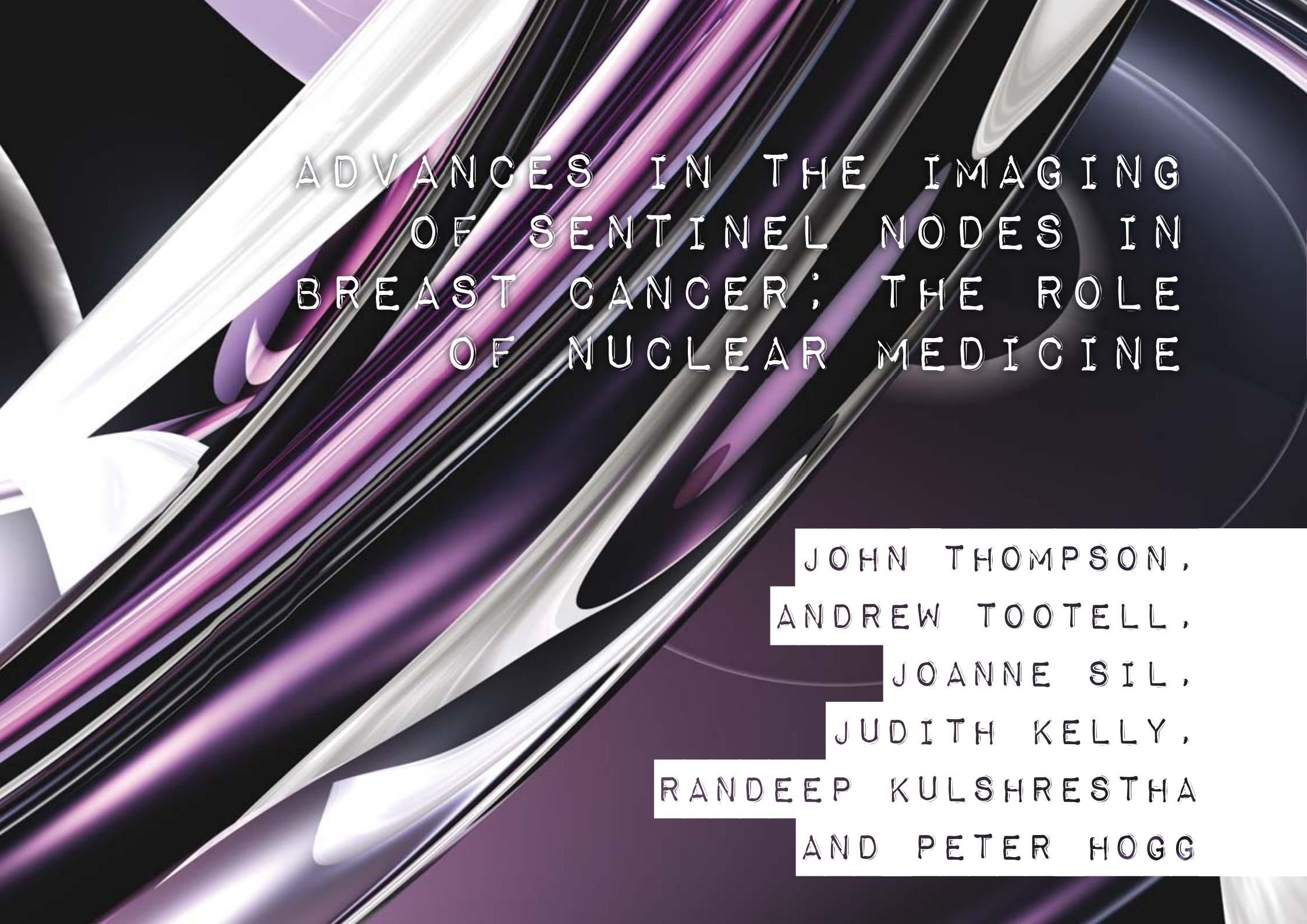

ADVANCES IN THE IMAGING OF SENTINEL NODES IN BREAST CANCER; THE ROLE OF NUCLEAR MEDICINE

JOHN THOMPSON,
ANDREW TOOTELL,
JOANNE SIL,
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Assessing sentinel nodes is highly valuable in the early period of cancer, facilitating accurate staging and dictating the correct treatment pathway. What are the imaging techniques used in nuclear medicine to detect the sentinel nodes associated with breast cancer and what are the benefits of SPECT/CT?

INTRODUCTION

The evaluation of the sentinel node by nuclear medicine and subsequent removal by surgical intervention has applications in several different forms of cancer (penile, breast, multiple myeloma)[1]. Assessing sentinel nodes is highly valuable in the early period of cancer, facilitating accurate staging and dictating the correct treatment pathway. This review will focus on the imaging techniques used in nuclear medicine to detect the sentinel nodes associated with breast cancer, detailing the benefits of single photon emission computed tomography/computed tomography (SPECT/CT) in aiding surgery.

CANCER

Statistics show that rates of morbidity and mortality are reducing for the majority of cancers[2]. Early detection, raised public awareness, better screening programmes, and improved technology and treatment regimes, are all contributing factors. Breast cancer is a good example, where sentinel lymph node biopsy (SLNB) and SPECT/CT have enhanced the patient experience through an improved technique to allow reduced morbidity.

Cancer rates per annum have stabilised but detection rates can vary with the introduction of new diagnostic tools and variation in population sizes[2]. Survival rates have also improved in the prevalent population (those with cancer), but increased life expectancy raises the possibility of both disease recurrence and complications related to any treatment of the cancer. Therefore, consideration of the long-term effects of treatment is important to both the patient and those involved in their care. However, treatment strategies are not the same for every patient and are highly dependent on accurate staging of the cancer, where the presence or absence of secondary disease (lymph nodes local to the primary tumour or distant metastases) could determine whether the treatment was conservative or aggressive.

In the United States, the incidence of breast cancer is high, with 1 in 8 females affected. In the United Kingdom, the incidence of breast cancer is slightly lower, with 1 in 9 females affected; despite improvements in mortality rates only lung cancer is responsible for more deaths[3]. Although large numbers of patients survive the disease, it is clear that breast cancer still constitutes a great challenge in both diagnosis and treatment.

THE SENTINEL NODE

The lymph nodes local to, and on the drainage pathway of, the primary tumour are a common site for initial metastasis[4]. It had been accepted that the removal of all lymph nodes surrounding the primary tumour (the axilla in breast cancer) could be potentially curative, but it has since been discovered that spread of this nature is more akin to the advanced stages of disease and is not necessarily the case in the early disease, prompting a reconsideration of treatment strategies. Lymph nodes have been found to be disease free in 60 per cent of early breast cancer sufferers. Breast cancer treatment has seen a dramatic change, where lumpectomy can replace mastectomy, and SLNB has replaced total axillary lymph node dissection (ALND) unless lymph nodes are proven to be cancerous.

ALND was typically associated with high morbidity (painful lymphoedema, reduced arm motion and parasthesia) but SLNB may reduce these complications, thus improving the patient experience. There are also associated cost-saving benefits to long-term care if morbidity is reduced. Correct identification and evaluation of the sentinel node is, therefore, highly valuable.

Predictable lymphatic drainage was first identified in a 1977 study of penile cancer[5]. Lymphatic drainage was said to be predictable, involving a chain of lymph nodes (Figure 1)[6] where the first node in this chain, the sentinel node, indicates the spread of disease. A disease-free node indicates that the lymphatic system is clear of disease, but anatomical variation of lymphatic drainage can be a complicating factor and care must be taken to accurately determine the sentinel node(s)[6]. On occasion, there can be more than one sentinel node, depending on the lymphatic drainage pathway.

SPECT/CT IS REDUCING MORBIDITY AND OPERATING TIMES

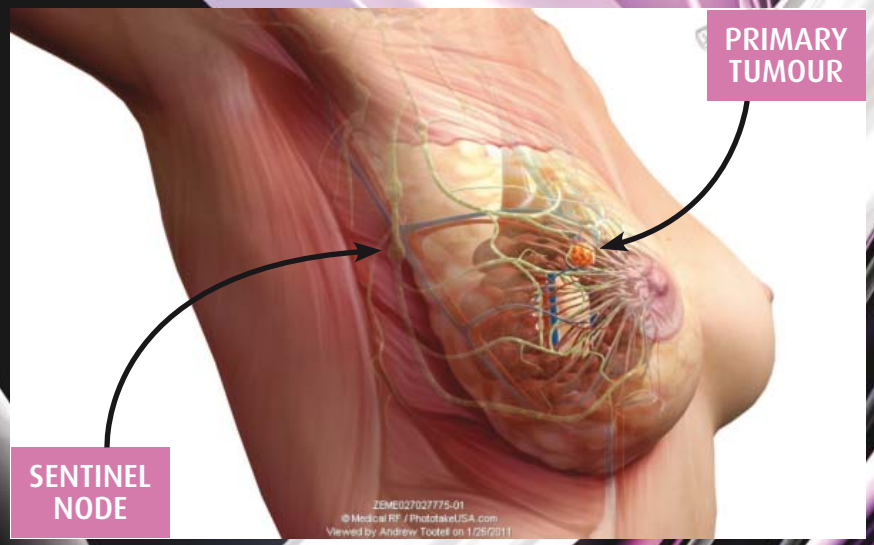

Figure 1. Lymph node location for breast cancer. An anterolateral view of the right breast. Illustration depicting cancer in glandular tissue and lymph nodes of the breast. Courtesy of Medical RF / Phototake http://www.phototakeusa.com/results.asp?Image=ZEME027027775-01 Accessed January 2011. Annotated by the authors.

Histology results achieved from SLNB have been used to plan surgery for a range of cancers, including breast, producing an optimal method for reducing morbidity in the node negative portion of the prevalent population[7]. Evidence of nodal metastatic spread would lead to node removal.

LOCATING THE SENTINEL NODE

Ultrasound can be used to locate sentinel nodes, but when used alone it is inhibited by an inability to confidently establish whether a lymph node is sentinel (first in the lymphatic chain) or not. A more suitable role for ultrasound is in guiding lymph node fine needle aspiration (FNA) or core biopsy, and is standard in some countries. This method has been shown to have good correlation with histological results of surgically removed nodes[8]. Ultrasound does, of course, have the benefits of no radiation burden, low cost and good availability, helping to maintain the established role it holds in the management of nodal involvement in cancer.

A variety of techniques for localising the sentinel node in relation to breast cancer exist in current practice, using various combinations of the following methods:

- 'Blue dye' injection intra-operatively
- Nuclear medicine $^{99}Tc^{m}$-colloid + planar imaging
- Nuclear medicine $^{99}Tc^{m}$-colloid + planar imaging + SPECT
- Nuclear medicine $^{99}Tc^{m}$-colloid + planar imaging + SPECT/CT
- Nuclear medicine $^{99}Tc^{m}$-colloid (No images acquired)
- Intra-operative gamma probe

The combination of blue dye, initially introduced for identifying the sentinel node in patients with malignant melanoma[9], and a radionuclide injection have proved to be optimal for sentinel node identification, showing great success in guiding surgeons in intra-operative biopsy (prior to histology), node dissection and surgical resection.

Despite the advantage of a visual stimulus provided by the blue dye, there was still no indication that the node was sentinel. Consequently, a non-imaging radionuclide technique was introduced to aid localisation and it became apparent that the two techniques were complementary[10] and successful in 81-100% of cases of melanoma[11].

Pre-operative sentinel node evaluation allows biopsy, followed by histology. Intra-operative evaluation allows biopsy (± excision) with histology results returned during the procedure. In both cases histology results dictate whether the node is removed.

Pre-operative localisation gives surgeons accurate numbers and locations of nodes, with the potential to perform less invasive surgery because less exploration is required. Operating time can also be reduced, which in turn may reduce complications and improve throughput of patients.

IMPORTANT ADVANCES IN NUCLEAR MEDICINE

Despite the ability of magnetic resonance imaging (MRI) to demonstrate physiology without radiation burden, nuclear medicine remains the modality of choice for capturing functional information. Since the introduction of 2-dimensional imaging to nuclear medicine, there has been a steady improvement in gamma camera technology due to the development of equipment and computer software. Planar imaging has been highly valuable for a wide range of pathology, although there have always been limitations such as the highly specific tracer uptake (no anatomical landmarks) associated with colloid imaging for sentinel nodes[12]. This type of difficulty has driven the advancement in technology to improve imaging.

SPECT was introduced in the mid to late 1980s to produce cross-sectional images of radionuclide uptake, allowing improved specificity, due in part to the ability of SPECT to differentiate between overlying structures. The popularity of SPECT led to the introduction of dual-headed gamma cameras and the technique became the standard for some investigations. Methods were developed to correct for radionuclide attenuation within the patient (eg Gd-153) to help quantify uptake and improve image quality.

SPECT/CT is the most recent notable advancement in nuclear medicine technology and is already popular for certain techniques. SPECT (emission data) is combined with CT (transmission data) on a single scanner gantry (Figure 2)[13] to provide an accurately fused data set of images showing functional and anatomical data.

The CT component of SPECT/CT has three distinct roles: attenuation correction (AC), lesion localisation and diagnosis. There are two different types of CT system available to support these roles: low-resolution (most suitable for AC) and diagnostic quality with the same functionality as a stand-alone CT scanner.

Figure 2. SPECT-CT Unit: CT Studies with SPECT. CT = computed tomography; SPECT = single photon emission CT. Courtesy of Siemens press pictures http://www.siemens.com/press/pool/de/pp_med/2005/sc_upload_file_mednm200504048_03_300dpi_1456207.jpg Accessed January 201113. Annotated by the authors.

ROLES OF SPECT/CT IN LYMPHOSCINTIGRAPHY

Attenuation Correction (AC)

Photons emanating from radioactive foci deep within the body are susceptible to absorption by the body before they can be detected by the gamma camera. Consequently, deep sited foci, such as a sentinel node, can go undetected in both planar and SPECT imaging negatively affecting the sensitivity and specificity of the diagnostic procedure.

CT (low-dose) can generate an attenuation map that, when applied to SPECT data, can correct for photon attenuation. This technique is now commonplace for certain patients and techniques in SPECT imaging; indeed, AC has been shown to have value for obese patients undergoing lymphoscintigraphy, with improved identification and a greater number of nodes being marked as sentinel.[14]

Lesion localisation and diagnosis

Whether using low-dose CT or diagnostic quality CT, foci of radionuclide

uptake can be more accurately localised when using SPECT/CT. Hybrid imaging has value when a SPECT acquisition fails to provide adequate anatomical detail. Lymphoscintigraphy is synonymous with this type of dilemma since the radionuclide uptake is highly specific. Precise registration of CT and SPECT data can overcome this where foci of uptake from SPECT data are superimposed upon the anatomical detail provided by CT. Acquiring CT data at a 'diagnostic quality' still permits a fused image; but the CT data are diagnostic in their own right and could be used to determine lesion/node position in isolation of SPECT data.

IMAGING THE SENTINEL NODE

Preoperative localisation of the sentinel node(s) involves the injection of a radiopharmaceutical, followed by imaging. Imaging can be 2D planar ± SPECT or ± SPECT/CT with the intention of determining:

- The number of lymph nodes
- The sentinel node(s)
- The location of the sentinel nodes(s)

Planar, SPECT and SPECT/CT imaging

Despite the recent development of SPECT/CT, many papers have described the usefulness of hybrid imaging for sentinel node detection. Warncke et al found that SPECT/CT better equipped surgeons to plan pre-surgical sentinel node identification, resulting in reduced operation times[15]. Accurate determination of node positions by SPECT/CT lymphoscintigraphy is highly valuable to the surgeon because it can facilitate a minimally invasive biopsy, thus reducing morbidity; it is also highly valuable for defining the involvement of supraclavicular lymph nodes, since this sub-group is associated with a poorer prognosis and may prompt an alternative treatment strategy[16]. Non-identification of the sentinel node, due to obesity and scattered radiation from the injection site, is a problem associated with planar imaging that SPECT/CT is able to resolve[14,17]. Additional hot nodes have been found in 13 per cent of patients compared to planar imaging, where the quality of planar imaging was reduced due to scattered radiation or the nodes had been on a less common drainage pathway[18]. The success of SPECT/CT is not limited to breast cancer; Even-Sapir et al report improved detection rates in cases of trunk melanoma[17].

Sentinel node technique – nuclear medicine

Many different combinations of injection and imaging technique exist for sentinel node identification and, despite a lack of consensus on the optimal method, there appears to be a robustness of these techniques, yielding a high success rate (>96%) for breast cancer[19]. Somasundaram et al outline a well considered technique, providing good justification and explanation[20].

Radiopharmaceutical administration

$^{99}Tc^{m}$-colloid is injected intradermally over the tumour or at the peri-areolar margin. The precise site is dependent on the nature of the primary cancer and which path of lymphatic drainage is the focus (internal mammary, extra-axillary or axillary). The

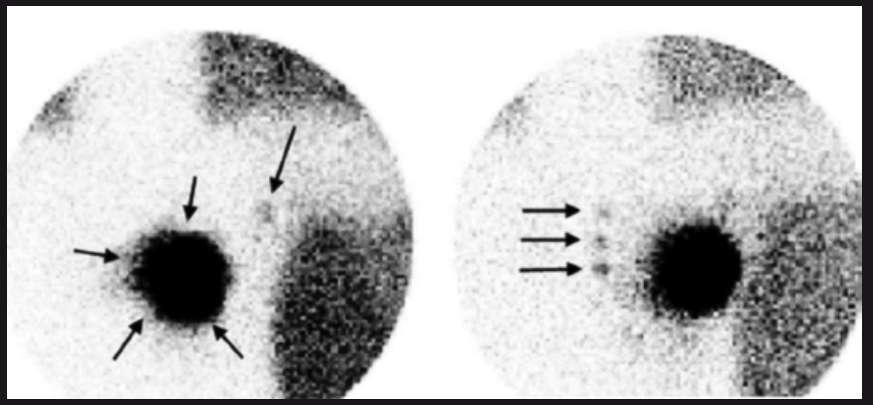

Figure 3. Static Planar image of axillary and internal mammary sentinel nodes. Planar scan of axillary (left) and internal mammary (right) sentinel nodes. Reprinted with permission from Aarsvold and Alazraki. Semin Nucl Med. 2005;35:116-128.[19]

Acquisition parameters	
Static planar imaging	**SPECT imaging**
High-resolution, low energy collimator 256 x 256 matrix 140keV energy peak, suitable window Acquired for set counts or set time	Low-energy, all purpose collimator 64 x 64 or 128 x 128 matrix 140keV energy peak, suitable window 360° rotation Step and shoot (20-30 seconds per frame)

Table 1. Example of static planar imaging and SPECT acquisition parameters.

IDENTIFICATION AND EVALUATION OF THE SENTINEL NODE IS HIGHLY VALUABLE

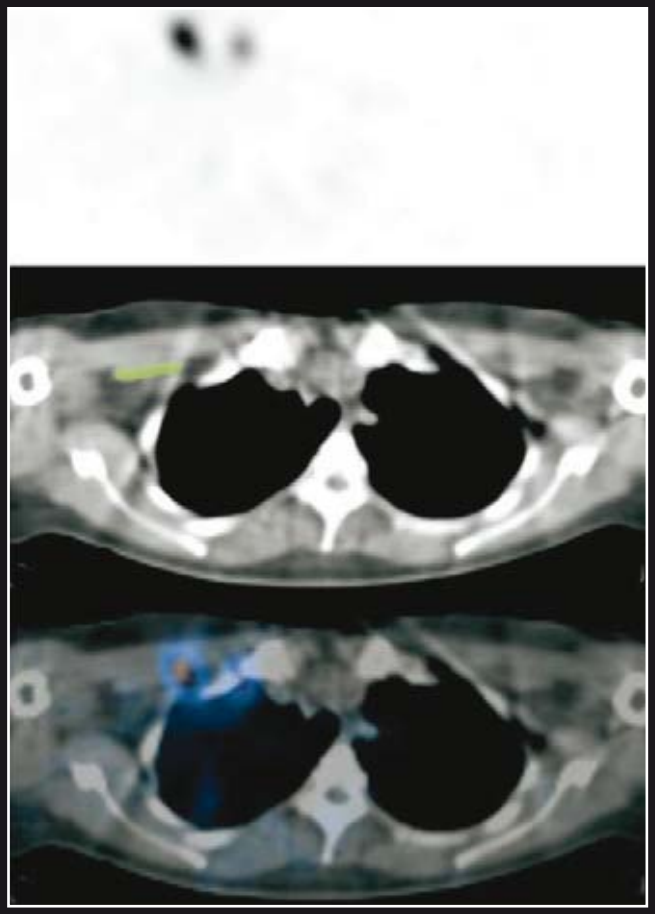

Figure 4: Cross-sectional SPECT image of the breast. Pectoralis minor muscle clearly visible on CT for cutoff between LI/II and LII/III. Top to bottom: SPECT; CT (pectoralis minor highlighted in green); fused SPECT/CT images, axial plane. Reprinted with permission from Husarik and Steinert. Semin Nucl Med. 2007; 37:29-33.[21]

colloid injection should be small in volume and activity (10-20MBq in less than 1ml), consist of a suitable range of particle sizes, and should be taken up quickly and trapped by the sentinel node to minimise uptake by secondary and tertiary nodes.

The number of primary lesions and previous surgery may dictate that the injection be split and administered in two sites. Other considerations include:

- An absorbent sheet to minimise the risk of skin contamination;
- Drawing air into the syringe to ensure the whole dose is administered and aid radiopharmaceutical dispersion;
- Massage of the injection site to encourage further dispersion.

Static Planar Imaging

Planar imaging (figure 3)[19] requires careful patient positioning to ensure all relevant nodes will be included. For breast lymphoscintigraphy it is important to include the shoulder, neck, axilla, costal margin and beyond the midline of the chest. Anterior and anterior-oblique images should be acquired immediately post injection. If the sentinel node fails to appear, then delayed imaging at 2-4 hours is recommended. Table 1 shows a typical set of acquisition parameters.

Figure 3 shows the specific nature of the colloid uptake and the associated lack of anatomical landmarks. Images of this type have limited value in isolation and many centres use a cobalt-57 flood source to provide a low-resolution transmission image to aid localisation. This was deemed suboptimal and led to investigation of the use of SPECT.

SPECT imaging

SPECT is a natural progression from planar imaging and, as before, should include the extent of the lymphatic chain of interest. Acquisition parameters can vary, but an example is shown in Table 1. The patient is usually supine and may require immobilising since the SPECT acquisition can take 20-30 minutes. Using a dual-headed gamma camera is preferable because it reduces acquisition time and reduces the risk of patient movement. Camera heads should be positioned as close to the patient as possible to maintain image resolution. Figures 3 and 4 demonstrate how the lack of anatomical landmarks provided by planar imaging and SPECT, make it difficult to be sure of the precise position of the sentinel node.

SPECT/CT imaging

Following a SPECT acquisition, a CT can be performed, without moving the patient, to enable anatomical detail to be overlaid on the foci of uptake. Accurate image registration allows precise localisation to occur. The patient must not be moved between the two acquisitions as image misregistration can occur with movement. As with all ionising radiation, the dose received by the patient must be a consideration. Table 2 shows that there can be a significant increase in radiation dose when using CT in addition to SPECT, and there should be good justification and clinical need prior to making a decision on its use[22].

Typical CT radiation doses (mSv)		
Body area	**Low-resolution CT**	**Diagnostic quality CT**
Chest	1	5.8
Abdomen and pelvis	1.5	7.1

Table 2. Typical radiation dose (mSv) associated with CT. Data from Griffiths et al.[22]

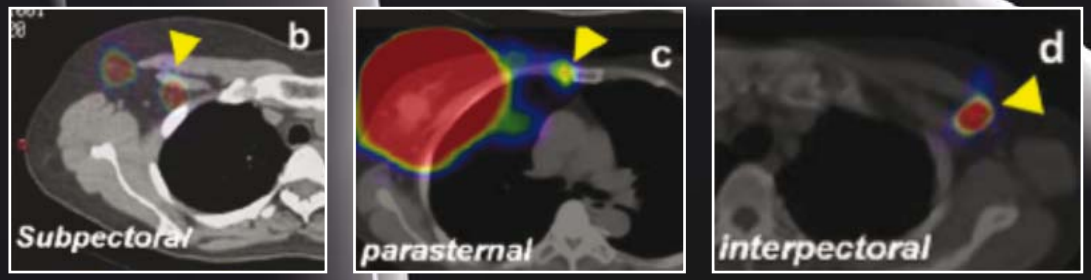

Figure 5. Fused SPECT-CT images of sentinel nodes. Sentinel node mapping using 3D SPECT/CT. The yellow arrows indicate the nodes: subpectoral; parasternal; interpectoral. Reprinted with permission from Ibusuki et al. Surg Oncol. 2009. [Epub ahead of print.][26]

Low-resolution SPECT/CT

When performing a low-resolution CT, the tube current is often fixed (1-2.5mA), allowing for no adjustment; but it does allow the operator to select the appropriate scan field of view. As with all acquisitions, this should include the entire lymphatic chain of interest, encompassing all foci of uptake identified on SPECT. A low-resolution CT provides an attenuation map for AC and a traditional CT image; and, despite its low quality, it can still be used to aid pre-surgical localisation[23].

Diagnostic quality SPECT/CT

Scanning patients at diagnostic quality is a more complicated scenario. Protocols vary greatly between both manufacturers and imaging departments and may also require adapting to suit patient needs. Due consideration should be given to each individual's clinical need[24]. A wide range of exposure parameters can be adjusted to optimise protocols for each patient (kV, mA, pitch, detector configuration (slice thickness), rotation time and image reconstruction). Axillary and internal mammary lymph nodes have an average size of 1cm and consequently a 5mm slice thickness is adequate for detection and localisation. For staging of breast cancer, the whole chest and abdomen are frequently scanned to assess for metastases within the lung and liver; narrower slice widths (0.5mm to 2mm on contemporary multi-slice CT) have been shown to increase detection rates for pulmonary lesions <1cm in size[25].

Low-resolution or diagnostic quality SPECT/CT?

In most centres, this choice would be limited by equipment availability. Buck et al considered the merits of each technique and favoured using a low-resolution technique for accurate localisation, unless there was a clinical need to perform a diagnostic quality scan[24]. Localising sentinel nodes and pulmonary lesions associated with breast cancer is also more acceptable with a low dose technique due to the low attenuating potential of the thorax and the high inherent contrast this provides. Figure 5 illustrates the benefit of a fused image for the localisation of sentinel nodes in a patient with breast cancer.[26]

Future developments

Promising results are beginning to emerge from pioneering work exploring the use of 'freehand SPECT'[27]. Using a higher dose than previously quoted (60-80MBq), an intra-operative handheld device yielded discovery of at least one node in 49/50 patients, sensitivity 98 per cent, whereas planar imaging achieved a sensitivity of only 84 per cent for the same 91 lymph nodes[27]. It was concluded that 'freehand SPECT' aided the surgeon with accurate 3D localisation detail for axillary nodes[28]. Whilst more studies are needed to support the validity of this technique, these initial results bode well for future developments.

CONCLUSION

Histological techniques play a critical role in lymph node evaluation for the planning of minimally invasive surgical procedures for the resection of cancer. For this to occur, the sentinel node(s) needs to be identified and assessed; if necessary, the node(s) may require accurate localisation and removal. Various combinations of pre-surgical and intra-operative localisation are available to surgeons, including blue-dye, ultrasound, hand-held gamma probes, and nuclear medicine imaging. Imaging in nuclear medicine has advanced dramatically in recent times and SPECT/CT now allows accurate fusion of physiological (radionuclide uptake) and anatomical data to aid the localisation process. SPECT/CT is thought to allow a more accurate pre-operative biopsy, reducing morbidity, while it is also reducing operating times by allowing the surgeon to localise nodes of interest more quickly.

For further reading, please see *The role and value of nuclear medicine in the imaging of sentinel nodes and breast cancer. eRADIMAGING.com website. Available at: http://www.eradimaging.com/site/article.cfm?ID=748&mode=ce. Published 10 February 2010.*

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GLOBALISATION OF HIGHER EDUCATION IN RADIOLOGIC SCIENCES: A NEW PARADIGM

SARAH BAKER

What is the future for higher education? Now is the time for the radiologic sciences profession to educate for global citizenship.

Within our global world, higher education is in a state of transition. A wide range of initiatives with potential ramifications for higher education reform are underway that will most likely impact radiologic sciences. A call for increased accountability, uncertain funding for higher education and international competition are among the demands we face in our global world[1]. The future of the radiologic sciences profession is global. We can no longer afford to fine-tune our existing educational policies; the time has come for an entirely new conceptual approach to radiologic science education. To meet the demands of the future, radiologic sciences professionals will need new and improved knowledge, not only to ensure top quality patient care, but for the good of society as a whole.

While globalisation can be defined in a multitude of ways, most would describe it as the growing integration of economies and societies around the world[2]. Included within this definition is the accelerating mobility of goods, services, labour, technology, and capital[2]. While globalisation is not new, the current pace of globalisation is being accelerated by technological advancements. The field of radiologic sciences has been at the forefront of technological change, yet our educational standards, delivery, mobility, and efforts towards globalisation have been slow to evolve. Globalisation of the radiologic sciences field would allow not only for free market and economic trade of goods and services, but it would permit increased mobility of radiologic science students, faculty, and professionals which, in turn, could foster international partnerships. Such partnerships would allow for increased collaboration and co-operation between and among countries, increasing our knowledge base and positively impacting patient care. In short, now is the time for the radiologic sciences profession to educate for global citizenship.

According to the United Nations Educational, Scientific, and Cultural Organization (UNESCO), the capacity of the world's educational systems has more than doubled in the past 43 years, with a six-fold increase in higher education or tertiary students during this time. The provision of tertiary education has been dominated by six countries, with the United States leading the way, followed by the United Kingdom[3]. Boasting the world's largest radiologic technology credentialing organization - the American Registry of Radiologic Technologists (ARRT) with over 300,000 registrants - one might surmise that the United States is poised to lead our profession into global citizenship[4]. And yet, entry level education and certification for radiologic technology in the US does not currently require a college degree. It is anticipated that by 2015, an associate degree will be required as the minimum pathway to ARRT certification[5]. Meanwhile, education levels among radiographers within the UK is at the Bachelor of Science Honours (BSc Hons) level. As Professor Hardy so eloquently stated, "The future of imaging will demand the radiography profession and its educators to think innovatively and open its mind to new ways of working[6]." She went on to note that this may be a challenge, but the potential exists for greater rewards, such as higher quality imaging and improved care for patients.

The current president of the International Society of Radiographers and Radiological Technologists (ISRRT), Dr Michael D Ward, has echoed similar thoughts on advancing the global profession of radiologic sciences. Among Dr Ward's goals is the global expansion of education within our profession, with sharing of best practices models of education and curricula. Additionally, he looks for better co-operation and communication with international radiologic science organisations to address such items as medical imaging, health care, and increased research partnerships. These goals, along with the establishment of an international radiologic technology programme accreditation process, are aggressive initiatives, but are attainable in light of current higher education climate and reform initiatives[7].

THE EXPANSION OF ROLES FOR RADIOGRAPHERS HAS BEEN STIFLED IN THE USA

CURRENT HIGHER EDUCATION REFORM CLIMATE

For over a decade, European countries have been engaged in reconstructing their higher education systems. This has, in part, been undertaken to create a greater degree of

convergence, with a goal of creating a European Higher Education Area (EHEA). While voluntary, this movement has been gaining supporters and has now been dubbed 'The Bologna Process.'[8] The 'Bologna' moniker was chosen in recognition of Europe's oldest university, located in Italy, where educational ministers of then 29 countries first agreed to action lines that would bring down educational borders. These ministers of education agreed in June 1999 to the goal of the creation of a European Higher Education Area (EHEA) by 2010[9]. The initial priorities of the Bologna Process were made official with the ministers' signatures on The Bologna Declaration.

Incentives for this process appear to be economic recovery, initially emphasised after World War II, and the need for closer cooperation among European nations[9]. In more recent times, The Maastricht Treaty on the European Union in 1992 identified the European continent's aspirations for a resurgent role in the world[8,10]. While higher education was a minor part of this document, the treaty did recognise that the European economy was knowledge-based, and thus supported a system of generating and distributing knowledge[8]. In 1997, the Lisbon Convention sought to facilitate the evaluation of foreign educational credentials. The immediate precursor to the Bologna Declaration was the Sorbonne Treaty, signed in 1998 by education ministers from the United Kingdom, France, Germany, and Italy[8,9].

The major impetus behind the Bologna Declaration was the emphasised role of higher education in supporting European economic growth and the international resurgence of the Continent[11]. Among a multitude of goals, the Bologna Process seeks to synchronise participating countries' university degree systems. The ultimate goal, however, is to create an EHEA in which students and faculty members are able to move about freely, from institution to institution and across nations[12].

While the United States may be a leader in per-student higher education spending, the return on this investment is lacking. America ranks abysmally when it comes to higher education completion rates. US state and local governments spent over 85 billion dollars funding public higher education in 2008, yet statistics show that only 56 per cent of first-time, full-time students in the US will receive a degree within six years[13,14]. These failing numbers are likely to yield drastic consequences for American's economic future.

Cliff Adelman, a former research analyst at the US Department of Education, has suggested that the United States should look to Europe in its quest for accountability. He argues that the Bologna Process offers some common sense solutions to the struggle to define what students should be learning and to create a better pathway through the US higher education system[8]. In the US, the Lumina Foundation for Education is also enamoured of the Bologna Process and the European process aimed at standardising what a college degree means across the continent[15]. The Lumina Foundation, an omnipresent force in American higher education and its reform, has made exploration of Bologna's potential application in the US a priority. Work is currently underway to create a Degree Qualifications Profile defining what graduates should be able to know and do when they receive an associate, bachelor or master's degree, regardless of what US institution they attend[15]. In January of 2011, the Lumina Foundation released a draft of its Degree Qualifications Profile, which will allow colleges, accreditors, and others in the United States to test and refine what degree recipients should know and be able to do[16].

The Bologna Process has yielded the Tuning Project, which is raising expectations for accountability. The major expectation is of ongoing curricular reform geared toward development of learning outcomes[9]. Tuning provides an approach to redesign, develop, implement, evaluate and enhance quality in degree programmes[17]. The name 'Tuning' was chosen to reflect the idea that universities do not and should not look for uniformity or any sort of unified, prescriptive or definitive European curricula in their degree programmes, but should instead look for points of reference, convergence and common understanding. Thus, Tuning focuses on educational structures located within higher education institutions (and academic staff), with emphasis on the subject area level, ie the content of studies. This process will allow higher education institutions to examine curricula in terms of structures, programmes, and actual teaching, in which the required academic and professional profiles and needs of society will play an important role[18]. A major aim of the Tuning Project is to contribute to a framework of comparable and compatible qualifications, described in terms of workload, level, learning outcomes, competencies, and profile[18]. Statements of learning outcomes are to be defined in subject areas, looking at core knowledge, supporting knowledge, and communication skills[8].

In the first phases of the Tuning Project, representatives from nine subject areas, including nursing, arrived at a common language to describe curricular goals. They were soon followed by representatives from sixteen other degree fields, radiography among them[8]. The field of radiography was identified as one of the Socrates Thematic Networks which

will incorporate Tuning methodology. The Thematic Network is known as HENRE. (Higher Education Network for Radiography in Europe)[19]. With this action, the stage appears to have been set for educational reform for the field of radiography in Europe. The combination of these forces (Bologna, Lumina, and Tuning) might well impact radiologic science education.

IMPLICATIONS FOR RADIOLOGIC SCIENCES

The implications of this work for changes to the future of radiologic sciences education are numerous for both the United States and the United Kingdom. The time is right to shift the educational paradigm from teaching to learning. Such a shift, along with a sharper focus on defining what future radiologic science students and professionals should know, understand, and be able to demonstrate, is imperative. The process of defining student learning outcomes involves the creation of a common standard to identify the competencies for our variety of degree levels and modalities. These standards, in conjunction with the development of a standard international nomenclature, will enhance international mobility of students, educators and radiologic science professionals.

In the United Kingdom, roles for assistants, and all three levels of both therapeutic and diagnostic radiographers have expanded considerably over the last decade, yet tensions and inconsistencies between boundaries still exist[6,20]. Meanwhile, in the US, the expansion of roles for radiographers has been stifled, in part due to the levels of education. While the newly created position of the radiographic assistant holds promise in the US, this expanded role has also met with tensions and inconsistencies across US state lines.

The future direction of the radiologic sciences profession in both the United Kingdom and United States should include a combining of forces and utilise the synergy of professional and educational talents. Such an effort would entail a close examination of educational and professional standards. Among other things, this might include an overhaul of the 'Standards of Proficiency for Radiographers' and 'Standards of Education and Training in the UK[21,22], while the US might overhaul accreditation and credentialing standards. The time is now upon us to think innovatively and do what is best for quality patient care within the radiologic sciences.

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RADIOLOGY ACCREDITATION IN THE UK: THE THEORY AND THE REALITY

MELANIE HIORNS

Quality accreditation has an increasingly high profile. But is it just another certificate to go on the wall in radiology services' reception? Or does it genuinely bring something new to standards and to patient care?

Accreditation is slowly but surely moving into the mainstream, both in healthcare and in other industries. In the UK, the Imaging Services Accreditation Scheme (ISAS) was opened for registration in June 2009 and the first Radiology Departments are now in the process of being accredited. However, many departments are taking a 'wait and see' approach. Questions such as, 'What's the point?', 'Is this going to become the norm?', 'How hard is it?', 'Does it make any difference?', 'Is it worth it?' and 'Will we have to?' are asked commonly. This article explores the bigger picture about accreditation and the accumulating international evidence base that going through an accreditation process changes practice and improves care, but also describes a personal experience of going through the ISAS accreditation process first hand and what it really means in practice.

In 2006 Braithwaite et al stated: "Accreditation has become ubiquitous across the international health care landscape. Award of full accreditation status in healthcare is viewed, as in other sectors, as a valid indicator of high quality organisational performance. However few studies have empirically demonstrated this assertion. The value of accreditation therefore remains uncertain and this persists as a central legitimacy problem for accreditation providers, policymakers and researchers."[1]

Two years later, Greenfield and Braithwaite further commented, "Accreditation, quality and continuous improvement have become an intrinsic part of the discourse and activities of health services. Internationally dating from the 1970s, health care accreditation programmes and accrediting organisations have emerged and developed. There are now many national accreditation organisations and an international body, the International Society for Quality in Health Care (ISQua) which has enrolled members in over 70 countries." [2]

This work by Greenfield and Braithwaite is the largest international study to date systematically reviewing the impact and/or effectiveness of accreditation. The review included a range of health accreditation schemes, including hospital accreditation, and was not confined to imaging, which is a relatively recent entrant into the accreditation arena. Topics considered included professional attitudes to accreditation, promoting change, organisational impact, financial impact, quality measures, programme assessment, consumer views or patient satisfaction, public discourse, professional development, and surveyor issues.

Two consistent findings were recorded: that of accreditation promoting change in the organisation, and in promoting professional development. The activity of preparing and undergoing accreditation has been shown in several studies to promote change in health organisations[3,4], particularly with respect to organisation and safety. In the studies reviewed, the positive outcomes included the chance for staff to reflect on, and become engaged in, the operation of the organisation; the introduction of continuous quality programmes, improved documentation, improved safety and improved review systems. However to balance this accreditation was not shown to *ensure* high-quality care but was positively associated with some measures of quality. Yet, accredited hospitals showed significant positive change in six defined areas, which was not recognised in non-accredited organisations.

Pomey et al[3] describe how the context in which accreditation takes place, including the organisational context, influences the type of change dynamics that occur in Healthcare Organisation (HCO). They found that while accreditation itself was not necessarily the element that initiated change, the accreditation process was a highly effective tool for helping to introduce continuous quality improvement programmes to newly accredited or not-yet-accredited organisations; creating new leadership for quality improvement initiatives; increasing social capital by giving staff the opportunity to develop relationships; and for fostering links between HCOs and other stakeholders. They concluded that the accreditation process is an effective leitmotiv for the introduction of change but is nonetheless subject to a learning cycle and a learning curve. Institutions invest greatly to conform to the first accreditation visit and reap the greatest benefits in the next three accreditation cycles (three to 10 years after initial accreditation)[3].

WORK OUT YOUR TIMESCALE AND DOUBLE IT

So how do these findings translate into, specifically, radiology accreditation programmes across the world? Accreditation has been in place in North America for a number of years. There are two major programmes, one run by the American College of Radiology[5], and another by the Joint Commission (an independent, not-for-profit organisation that accredits and certifies more than 18,000 healthcare organisations and programmes in the United States[6]).

Currently, accreditation is confined to advanced imaging techniques such as CT and MRI. This, in part, has been driven by reimbursement policies that may require accreditation and to meet the criteria of CMS (Centres for Medicare and Medicaid Services) [7], state or federal government, or third-part payers. Medicare is a social insurance programme administered by the United States government, providing health insurance coverage to people who are aged 65 and over, or who meet other special criteria. The ACR outlines how all MRI, CT, PET, breast MRI and nuclear medicine facilities that bill under the Medicare fee schedule, must be accredited by January 2012 to receive Medicare payments for the technical component of these service[8]. Accreditation is also recognised for its value as a marketing tool and is clearly promoted as such.

In Australia and New Zealand, there is a voluntary accreditation scheme jointly administered by The Royal Australian and New Zealand College of Radiologists (RANZCR) and the National Association of Testing Authorities (NATA), which commenced in May 2004, and is open to all diagnostic imaging providers that wish to apply. However, sites that offer MRI services that are eligible for Medicare rebates are required by the Commonwealth government to participate in the RANZCR's MRI Accreditation Registration Programme.

Mandatory accreditation schemes exist in South Korea and Finland, although these have a different configuration to that being developed in the UK.

In the UK, accreditation is only now starting to become established and is still a long way from being a mandatory requirement, although it is certainly possible that this may happen in the future. However, in parallel with schemes elsewhere in the world, it is appropriately influenced by the guidelines of the professional colleges (Royal College of Radiologists and the Society and College of Radiographers). Unlike elsewhere, the actual scheme is exclusively run by a third party, the United Kingdom Accreditation Service (UKAS), which is 'the sole national accreditation body recognised by government to assess, against internationally agreed standards, organisations that provide certification, testing, inspection and calibration services'[9]. UKAS is a non-profit-distributing private company, limited by guarantee. It is independent of government but is appointed as the national accreditation body by the Accreditation Regulations 2009 (SI No 3155/2009) and operates under a memorandum of understanding with the government through the Secretary of State for Business, Innovation and Skills. The Imaging Services Accreditation Scheme sits within UKAS. Background to the development of the Imaging Services Accreditation Scheme is outlined by Garvey, et al.[10]

So to take this further, how do some of these findings translate into the role for an imaging services accreditation scheme in the UK in the current political climate? The principles underpinning the original Radiology Accreditation Programme were drawn from those referred to in the 2007 White Paper 'Trust, Assurance and Safety: the regulation of health professionals in the 21st Century'[11]. More recently (2010), the National Health Service (NHS) White Paper 'Equity and Excellence: Liberating the NHS'[12] set out the Government's long-term vision for future healthcare; that of a patient centred NHS in which the drive for better health outcomes is clear. It recognises the financial challenges the NHS faces and the role QIPP (Quality, Innovation, Productivity and Prevention) will play in supporting the NHS in identifying efficiencies, whilst driving up quality. An editorial in the *British Medical Journal* in 2008 outlined how most recent NHS reforms have been designed to improve efficiency and productivity **and** also to improve the quality of care.[13] That trend is ongoing.

Quality is becoming the leading driver in healthcare reform going forward, representing a move away from performance targets per se. This aligns with the core purpose of accreditation, being the formal recognition that an imaging services provider has demonstrated that it has the organisational competence to deliver against key quality measures across four domains which include 'Clinical', 'Facilities, resource and workforce', 'Patient experience', and 'Safety'. These four domains comprise the 'Standard' which has been designed to

- Be patient focussed;
- Cover the functions and systems of a whole diagnostic imaging and interventional radiology service;
- Address the dimensions of quality and support quality improvement.

'Outcomes' are the indicators by which the quality and effectiveness of a service can be assessed. The NHS Outcomes Framework[14] published in December 2010 sets out the outcomes and corresponding indicators that will be used to hold the new NHS Commissioning Board to account and, as such, represents a clear message about the importance of verified outcomes going forward in health policy. Each of the 31 standard statements across the four domains in the ISAS Standard has an associated outcome measure of the individual service's design and choosing. This aligns with the direction of travel of health policy in the UK.

It must, therefore, be hoped that participation in the ISAS programme in the UK will, in itself, be some form of evidence that radiology departments may, in future, submit to the various regulatory bodies such as the Care Quality Commission (CQC), who are the independent regulator of care provided by the NHS (and also of local authorities, private companies and voluntary organisations).

ACCREDITATION ON THE GROUND

The radiology department at Great Ormond Street Hospital for Children has been associated with the emerging accreditation programme since early 2007, when it became one of five pilot sites for the Radiology Accreditation Programme (RAP) across England, and since 2009 has been formally committed to the resulting ISAS accreditation scheme. Ten imaging services have been in the first wave and one has just received accreditation along with Great Ormond Street. One other NHS Trust, having had assessment visits, is anticipating formal accreditation imminently.

The ISAS website[15] gives a vast amount of user-friendly information on what accreditation is about, pre application information and preparatory workshops, a

detailed description of the 'The Standard' and all that it entails[16].

In preparing for assessment, an organisation must first outline how much of its service it wants to be considered for accreditation – this is called the 'scope'. Usually the whole service would be included, but there may be instances where only part of the service is included in the scope: for instance, if a new part of the service has only recently been established and this is not ready for the first round.

The Standard comprises four domains. A total of 31 'standard statements' are spread across these four domains, and each standard statement addresses one aspect necessary for the provision of the service. A list of criteria indicates the structures and processes necessary to deliver each particular standard statement. For each criterion, indicative examples of acceptable evidence is given.

The service will then work on its evidence over the upcoming months (typically a year) and will upload it to ISAS via the web-based tool. Once the evidence has been submitted, it is assessed and, if sufficient and appropriate evidence has been provided, a site visit will follow. The assessment team will usually comprise a radiologist, a radiographer, a lay member and a professional UKAS assessor.

Our experience at Great Ormond Street was that initially we completely underestimated the amount of work involved in the whole process. Gathering the evidence is a huge task; we found that it was not so much that we were not doing a lot of good things already, but more that we had never written it down in an organised and joined-up way. Whilst this may appear rather banal, it became evident that our processes were basically safe, and we hopefully offered a high quality, patient focussed and forward looking service but our documentation, whilst present, was scattered in different places (sometimes in people's heads). Everyone knew what they were doing and were doing it well, but this knowledge had been learned over many years. Someone arriving new wouldn't have one place to go to find out about our polices, procedures and protocols. Our document control was not as good as it should have been (and now is) and some areas of the department were doing things in a slightly different way to other areas.

To balance against this, we realised that there was almost nothing we were not already doing that we should have been. We were well ahead of the curve in our patient surveys, our audit programme, our risk management and in our patient-oriented practice. Financially, we were in good order and our management structure was effective and safe.

After a false start, we brought together a group of five key members in the department to lead and to champion the accreditation work. These included a consultant radiologist (who was also the clinical unit chair for the division and thus had professional radiology input, but also had an overview of the wider role of radiology within the hospital and of the hospital's structure and policies), the radiology service chair, the radiology service manager, the

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lead radiology superintendent, and the departmental personal assistant (PA). The PA was invaluable in collating all the evidence once it had been submitted to her and organising it on the web based tool. She was also able to keep an overview of what information was missing, who was supposed to be providing it, and to do the chasing.

The radiology superintendent co-ordinated the activity of a wider group of modality superintendents with respect to their various modalities, and for the documentation and policy writing relating to those areas. The consultant radiologist took responsibility for some of the higher level organisation information and for many of the criteria in the clinical domain. The radiology service chair and service manager co-ordinated everything else. Early in the process, one of these five names was written against every single one of the 131 criteria, so it was very clear who was responsible for that criterion. Tentative dates for completion were added, which were reviewed at least once a month. By the end of the evidence gathering phase, every single person in the department had been involved in accreditation in some way. The task of collating the evidence would have been impossible without this cascade effect.

Once the evidence had been reviewed and accepted, the dates were set for a two-day site visit. This process really starts the adrenaline flowing and it was a time of great coming together for the department to prepare for this, knowing that any one of the 70 of us could be asked a question, or asked to demonstrate something. Many of the staff who had been aware of the accreditation work going on suddenly pricked up their ears and, in the last few weeks, there was a real momentum. People would ask me what it meant to be accredited and would it matter? I could only reply that I hoped it would make us special and would allow us to prove unequivocally that we are a good department, rather than just believing we are.

The two-day visit itself went off uneventfully. Many of the staff were outstanding (and this was recognised and commented on by ISAS) and were genuinely proud to have been involved with it and to be able to show our department, and what we have achieved, to 'outsiders'. The feedback was given straightaway on the second afternoon and the senior management was requested (by ISAS) to be present as they are the

ones who ultimately have responsibility for a safe, quality, hospital. The chief executive attended, which certainly raised the bar. We have some 'mandatory' actions to fulfil (which we absolutely expected and is the norm) and we submitted evidence with respect to these in January 2011.

So has it been worth it for us? Yes, definitely. We have developed ourselves, and strengthened our relationships with our users (both clinicians and patients). We have made a huge step change in how we challenge our own practice and the evidence we use to demonstrate our good practice. We have improved our documentation beyond measure, and have examined critically all our processes. We believe we deliver a safer quality service to our patients. But it has been hard work.

For other departments considering accreditation these are our top tips:

- Take full advantage of all the pre-application information, advice, and pre-application workshops that ISAS can offer.
- Have a really thorough look at the Standard and all the standard statements in each of the four domains so you know the size of the task.
- Work out your timescale and double it – realistically, it is probably going to take a year of preparation.
- Convene a core group of people who really want to achieve this and make sure your senior management are fully supportive and understand the benefits.
- Distribute the tasks clearly so individuals know what is expected of them personally, and keep a 'project plan' up to date.
- Liaise with ISAS throughout the process so you know that you are heading in the right direction.
- Know that the first time you do anything is the hardest and keep going.
- Keep the faith that this process will make you a better department – both for your staff and for your patients.

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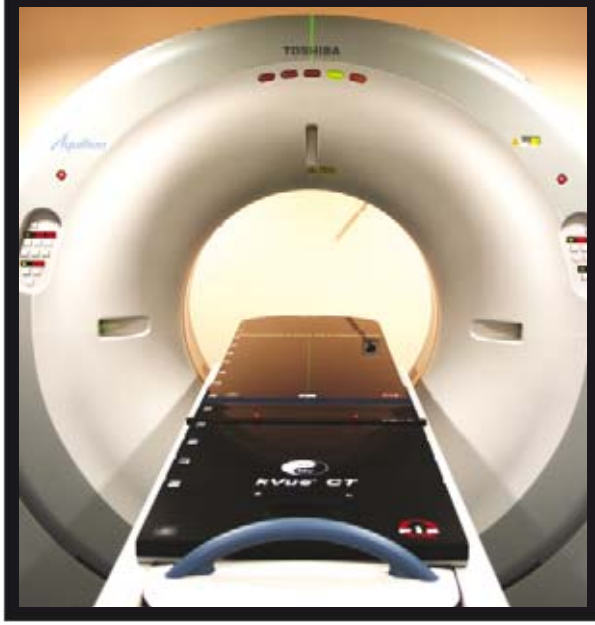

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EDUCATING THE RADIOGRAPHY WORKFORCE: A DIVERSE CHALLENGE

IAN HENDERSON

How should the workforce of the future be trained? How far will role development and skills mix go? What skills will radiographers need?

At the present time, UK radiography education, in common with other non-medical health disciplines, is largely delivered by the higher education (HE) sector. This encompasses pre-registration entry level programmes entirely, most of the post-registration and postgraduate offerings and most of the 'non-professional' level provision, ie the assistant level workforce. Some post-registration provision is delivered by the independent sector and there is a considerable amount of practice based, or in-house provision. For the assistant practitioner and support workforce, again there is some accredited practice based, or in-house training, and also some delivery by the further education (FE) sector.

As a general overview, both pre and post-registration education and training are, allegedly, related to workforce planning or developmental needs. In England, currently, this is manifested through a commissioning process, where pre-registration student numbers are contracted to higher education institutions (HEI) by strategic health authorities and, to some extent, post-registration numbers are also contracted in this way. This, however, is a generalisation since the arrangements for post-registration provision are by no means consistent across the country. In Scotland, Wales and Northern Ireland, arrangements follow a more conventional or academically focussed system.

It is the case then that HEIs offering radiography, may offer both diagnostic and therapeutic, will commonly offer a range of post-registration or postgraduate provision, and may offer provision for training the support level workforce[1]. This scenario provides a number of challenges in terms of delivering an appropriate product in a rapidly developing clinical landscape, whilst resourcing provision in an increasingly purchaser provider environment.

The future effectiveness and, indeed, relevance of imaging and radiotherapeutic professionals is at stake if education and training is unable to maintain alignment with professional needs. The situation warrants scrutiny at a time when natural evolutionary change seems to be accelerating significantly[2,3,4].

So what does the future hold?

A BIT OF BACKGROUND

The educational landscape for radiography has changed significantly in 25 years in terms of both entry to the profession and for post-qualifying education; from the centralised curriculum and assessment of the College of Radiographers, to an HE based system. Of course, this is not news to most in the profession, but the reason for mentioning it is to point out that, in real terms, it is not so long ago. There remains a high proportion of the profession who trained in that earlier period, who are still around, many of them highly influential in how the profession has evolved. The move to HE based provision, a consequence of the then government's 'Working Paper 10'[5], was a massive shift in the culture of radiography education. In the 20 years since then, there has been accelerating change in the parameters within which radiographers work, affected by such diverse influences as technology, health policy, national demographics, and public expectation.

Of course, these factors have always played a part, but it may be argued that, in this period, the explosion in computer based technology and the critical influence of healthcare financing, to name but two, have transformed fundamentally aspects of how imaging and oncology services operate and are delivered. There is no reason to suspect that this rapid evolution will slow. Arguably, the changes of recent years, and the change yet to come, will transform educational arrangements for radiographers every bit as much as those of Working Paper 10[5].

How do the various elements of the equation fit together? To start with let us examine how the education sector relates to the clinical environment.

PARTNERSHIP, OR UNEASY BEDFELLOWS?

In the wider world, it could be said that academic and professional elements produce

HEIS ARE UNFAMILIAR WITH DELIVERING PROGRAMMES BENEATH UNDERGRADUATE LEVEL

the total picture of how a profession exists and evolves[6,7]. They are inextricably linked in a partnership engaged in the process of developing and applying practice through education, research and collaboration with the aim of ensuring an ongoing drive for excellence. Benson[7] indicates that one of the criteria for a profession is that there must be a professional body which – *'must set the ethical rules and professional standards which are to be observed by the members'* – thereby acting as a focus for the integration of theory and practice.

Educational programmes develop undergraduates to become members of a profession and, in that process, students will usually undertake work placements within that industry. University departments engage in research, commonly in collaboration with and, indeed, receive funding from the industry with which they are associated. The notion of partnership therefore, if idealistic, is explicit in both educational and research terms.

In radiography, these components all exist, but does the partnership notion really work in the idealistic sense? Anecdotally, it seems that there is often a divide between theory and practice, as if the two were linked in only a tenuous fashion. Undoubtedly, many very effective relationships exist between the clinical and academic sectors, though often this may extend only to limited strata of activity, for example, training of undergraduate students, or linkage for delivery of professional development programmes. This can lead to the perception of a purchaser provider type relationship, rather than a partnership. Whilst it is true that HEIs are obliged to liaise with the clinical sector in the periodic process of developing or reviewing curricula, how often is the clinical sector at ground level, involved in collaborating in research initiatives? How much ownership does the profession have of the development of its evidence base? Current evidence indicates that there is a limited degree of activity in these areas and there are a number of reasons why this may be[8].

For example, radiography has traditionally been seen as a 'hands on', practically oriented discipline and this could be considered an ingrained culture; HE sector involvement in radiography education, providing the opportunities for collaboration, is a relatively recent occurrence; the operational linkage with the radiological profession has traditionally been essentially subservient, with much of the practice related research medically dominated; the structure and budgetary mechanisms of the National Health Service do not necessarily facilitate the establishment of department level research initiatives. These factors are general and it would be quite wrong to imply that there are no examples of effective partnerships and collaboration. However, the pervading culture does not readily support the sort of situations that exist more commonly in the wider world.

WHY IS THIS A PROBLEM?

In a time of rapid change, adaptation and evolution of the profession have to be driven coherently and strategically. Education should provide practitioners that are not only fit for practice, but fit to take practice forward. The clinical sector should be able to provide a strategic view of what it needs from professional education in the medium term, bearing in mind that a course developed now will produce its first graduates in at least three years' time.

Dealing with continuous transition in healthcare delivery and technology means that there is considerable scope for a mismatch of expectation if collaboration is not effective. In this context, it is fair to say that the academic world has a responsibility to have a clear perspective on emerging health policy and technology in order to respond proactively to prospective needs. The danger is, however, that if the 'cart comes too far before the horse', then educational effectiveness may be compromised. A largely diagnostic example of balancing such a transition, which could be termed 'transition stress', is the move from film-based to entirely digital imaging. This is a situation where HEIs had to shift from one substantial technology to another over a period of time, balancing the needs of students according to the environment in which they were training, in the knowledge that they may then go on to work in a another location where the arrangements were completely different.

The concept of transition stress is a common feature of dealing with change in a multi-factorial environment[9]. HEIs need to be ahead of the game, yet aligned to current reality. They need to be able to work with the clinical sector, yet the shape and culture of that sector may provide its own challenges. Notwithstanding the current economic climate, the projected changes in healthcare structure, delivery and workforce; and the continuing development in technology associated with both imaging and oncology, provide the main challenges to the education sector in both the short and medium term. The scope for change is massive.

CHANGING TECHNOLOGY

Imaging and oncology service development is driven by a variety of factors, but there is no doubt that technology is a major component of delivery in both disciplines. Indeed it has been said[10] that radiographers are the interface between the equipment and the patient, ensuring that the two come into contact in the correct way, with the correct outcome. Amongst health practitioners, it can be argued that radiographers occupy an unusual position in terms of how they are 'linked' to the equipment they use. This means that evolution in equipment design and function has a fundamental impact on radiographers and the nature of the demands on them in using it.

In the past 30 years at least, developments in computer technology have probably had the greatest impact on the technological aspects of how radiographers practice. Computerised systems are fundamental to how much of modern radiographic equipment functions, relying heavily on computer processing power in order to manage large amounts of digital data. An estimate of the significance of this is demonstrated by Moore's law[11] which, in 1965, predicted a doubling of computer power every two years. It is believed that the law continues to hold true today, indicating an almost exponential change in processing power that will probably not come as a surprise to radiographers who have been around for a while.

WHAT IS THE SIGNIFICANCE OF THIS?

The whole technology issue is an article on its own, but in précis we now have a scenario where many decisions or processes are no longer in the hands of equipment operators, where computer assisted diagnosis is a reality and where emerging technologies, such as molecular imaging, may change the face of radiology[12]. Without wishing to be too contentious, it may be argued that some imaging and oncology practices have already been deskilled by the intervention of modern equipment. What does this mean then to the scope and emphasis of radiographic practice and, in that context, how does education align with this change? Does a radiographer really need a degree in order to carry out many aspects of routine radiography? Or to put it another way, when assistant practitioners are evidently capable of carrying out much of the routine work, do radiographers still need to be taught the same skills set, or should the emphasis lie in areas where they can effectively exercise the clinical judgements associated with graduate level practice? The evolution of radiographic practice is also linked to the wider environment, health policy priorities and, of course, professional aspiration.

approvals undertaken by the College of Radiographers indicate that the UK's entry level education is not dramatically different[14] to that of many other developed countries. It can be legitimately argued that this is because role extensions are post-registration skills, taught usually at postgraduate level, but when does an evolving practice become a mainstream skill or, indeed, can it? And in that context, from a skill mix perspective, when does the practice of assistant practitioners influence the entry level training of radiographers?

The NHS Plan[2] and the recent white paper 'Liberating the NHS'[4], set out to change the face of healthcare in significant ways. Among other things they advocate skill mix, the shifting of services to the primary sector, and increased involvement of the independent sector in delivery. These features encourage the evolution that is already underway, so what do radiographers need to look like in the future if they are to deliver effectively in this environment? Specifically, how do they need to be trained and developed in order for this to happen?

THERE IS POLITICAL WILL TO BUILD THE BAND 4 WORKFORCE

HEALTH POLICY AND THE HEALTH SERVICE

The healthcare landscape is influenced by changing demographics, clinical research outcomes and political priorities. Alongside this, clinical practice evolves. In radiography, the most familiar phrases of recent years have surely been 'skill mix' and 'role extension/development' alongside, for slightly different reasons, continuing professional development (CPD) and advanced/consultant practice. All terms associated, quite explicitly, with modifying or evolving the roles of radiographers. Developed roles such as diagnostic image reporting, portal image evaluation, and an extensive range of others, have become widely regarded as completely acceptable - to the radiographic community at least - and are supported by robust research evidence to underline their credibility.

Like all evolution however, the correct circumstances must exist for it to occur and the unique structure and demands of the UK's National Health Service (NHS) have provided this. Witness the fact that radiographic reporting, for example, has hardly scraped the surface in most other countries globally[13], making it apparent that the UK is a bit of a rarefied environment. It is interesting to note then that recent international course

EDUCATING THE FUTURE WORKFORCE

The business, for that is what it is, of training and educating the radiographic workforce has conflicting demands. In order to deal with significant development and lead-in times, particularly for undergraduate programmes, the HE sector must have a very clear perspective on the health policy agenda, effective linkage with the clinical sector, and with those who commission training in whatever form; the market! How much the HE sector can push the practice agenda and how much it must follow is, of course, influenced by resources and, frankly, by market forces. In respect of post-registration education in particular, it is evident that despite the College of Radiographers' clear viewpoint on the radiographic scope of practice[15], there is limited commonality of view at ground level. In fact, there is considerable variation in the implementation of skill mix initiatives across the United Kingdom, often because of regional workforce priorities and/or local professional opposition[16]. The localisation of professional development priorities is further encouraged by the implementation of Agenda for Change requirements in respect of staff development through the NHS Knowledge and Skills Framework (KSF), meaning that clinical environments may have very specific demands for CPD provision, often unaligned with the traditional forms of post-registration programmes on offer.

The challenge for HEIs is to maintain alignment with the current scope of practice for entry to the profession, whilst anticipating future requirements; to provide effective, relevant CPD opportunities for radiographers that meet the needs of a diverse and fluid market; to contribute, where possible, to training the assistant level workforce, again in line with local requirements. So, quite a few variables there then!

What are the factors that impact on their ability to deliver on these elements?

PRE-REGISTRATION, ENTRY LEVEL PROVISION

Radiographer education at the entry level could be seen as the more stable component of the equation, at least currently. The challenge exercising many HEIs is how to minimise student attrition from programmes at a time when, in England at least, strategic health authorities are penalising them for failing to deliver higher completion rates[16]. Periodic programme review requires them to look five years into the future when the first graduates from a reviewed programme will enter the workforce. Will graduates be fit for practice in the environment that exists then? It is clear that many HEIs are taking great care to develop curricula that are forward looking and anticipatory, but a balance must be achieved. Too much, too soon risks a misalignment with existing needs. Too speculative and the misalignment may be further down the line. So, do these factors encourage conservatism in the design of curricula?

An example of this was the adoption over 10 years ago by some HEIs of the theory component of the College of Radiographer's intravenous (IV) administration programme in the anticipation that IV administration would become an entry level skill, but has it? Despite the fact that IV administration is now effectively a mainstream activity for radiographers, it remains essentially a post-registration skill. Knowing the style and rate of change remains a speculative process.

POST-QUALIFYING

In the post-registration/postgraduate arena, the situation is currently more dynamic. The demands of developing the workforce to meet a rapidly changing environment has required HEIs to operate in ways not previously associated with that sector, more responsive, more flexible, more cost effective. The clinical sector requires targeted, specific programmes that are accessible, tailored to their needs, and aligned with KSF or Skills for Health standards. They will pay for what meets service needs and that does not necessarily mean traditional postgraduate programmes.

Anecdotal evidence indicates that in many areas the number of students signing up for full postgraduate awards has dropped in recent years as students seek focussed programmes that will deliver a specific skills package in line with their CPD requirements. This requires a culture shift for many HEIs as they come to terms with a major change in the shape of post-registration delivery and their ability to respond must also take account of the fact that the market size for many programmes is not sufficiently large to ensure consistent viability. This, and the reduced emphasis on academic credits, has created an opportunity for independent providers who may meet a need not fulfilled by larger scale HEIs. The law of economy of scale does not necessarily apply in this situation.

ASSISTANT WORKFORCE

In many respects, this component of the workforce has been hardest for the HE sector to comprehend. Although standards for practice are defined, particularly through the College of Radiographers' Learning and Development Framework[17], educational arrangements are inconsistent, with no specific identified 'qualification' for entry to this group. Training arrangements range from in-house training schemes to NVQ programmes, BTECs, Foundation degrees, and a few things in between. Implementation of this tier of the workforce has been influenced by, amongst other things, financial pressures, radiographer availability, and strategic imperatives of clinical managers, meaning that it has been patchy in geographical terms and across modalities and disciplines. For example, assistants are well embedded in the mammographic screening workforce, though less than might be expected in radiotherapy, with some oncology managers questioning the need for assistant practitioners in their service. This has caused some difficulty for HEIs in identifying demand and sustaining programmes for assistants. It is also fair to say that many HEIs are unfamiliar with the business of delivering programmes beneath the undergraduate academic level.

It may be argued then that in this transitional period for development of the assistant workforce, there has tended to be a vicious circle of varying supply and demand. Nevertheless, it is quite clear that there is an evident political will to consolidate and build the band 4 workforce[18] and therefore the need to provide appropriate opportunities, both for initial training and subsequent development, cannot be ignored. This is potentially a major growth area for radiography education, so who delivers it? The HE sector which has the knowledge and expertise in radiography, or the Further Education sector, which has the ability to deliver effective and well supported programmes that meet the very specific needs of learners at this academic level?

THE FUTURE?

LP Hartley said 'the past is another country, they do things differently there' and, in this case, it may literally be true. The rate of recent change has been significant and gives some sense of what is to come. Looking ahead, the medium term prospect for radiography education is one of shifting emphasis. In general terms, policy direction suggests expansion of the band 4 workforce in a more directive manner than in the past[18]; possible contraction in undergraduate radiographer training, at least in diagnostic (already some evidence of this at the time of writing); increased interest in supporting post-qualifying training at all levels to facilitate skill mix developments and the restructuring of some services. What this means for the HE sector probably has two main facets.

Firstly, developing or expanding provision in 'pre-graduate' and post-qualification areas requires a degree of re-prioritisation and potential re-skilling. Whilst it is true

that many HEIs have already well embedded provision, others may have some work to do in this area. Training the assistant workforce in particular, has some specific challenges and there is a lot that may be learned from the further education sector. For example, delivering effective support for students at this level. Additionally, the whole business of providing post-qualifying provision, for all components of the workforce, in a range of different shapes and sizes, is a challenge, leading to:

The second facet, which relates to the development of an effective entrepreneurial, business oriented perspective. Again, it is true that many centres understand the significance of this. Actually achieving it is another matter. Effective delivery of post-qualifying programmes will be key to maintaining position in a competitive arena. In order to be successful, HEIs will need to be fast moving, responsive, adaptable and competitive; not attributes that have traditionally been associated with the sector. Systems to support different ways of interacting with 'the market' need to be in place and this needs to be effective and professional, if only because competitors in the post-qualifying market are not just other universities. The developing independent sector provision for CPD can react quickly and cheaply to demand.

Of course, health education has, and continues to operate on, quite a localised basis, dependent on the relationships that exist within a region. There is, therefore, a degree of generalisation applied in this discussion and, naturally, the different arrangements across the four countries of the UK are also significant. Nevertheless, the principles are applicable, as are the influencing factors.

The situation is in transition at the time of writing and therefore there remain some significant unknowns. For example, the specific arrangements for the commissioning of education in England. Following the government's decision to move commissioning to GP led consortia[19], the dissolution of primary care trusts and regional health authorities has led to a proposal to manage education commissioning through a new body, Health Education England, in conjunction with 'provider networks'. The end result may not be too different but, inevitably, there will be system changes for HEIs to deal with. One way or another, finance is the driver although, in some form, radiography education at all levels will continue. The things that will most need to change are operational structures and priorities, and attitudes.

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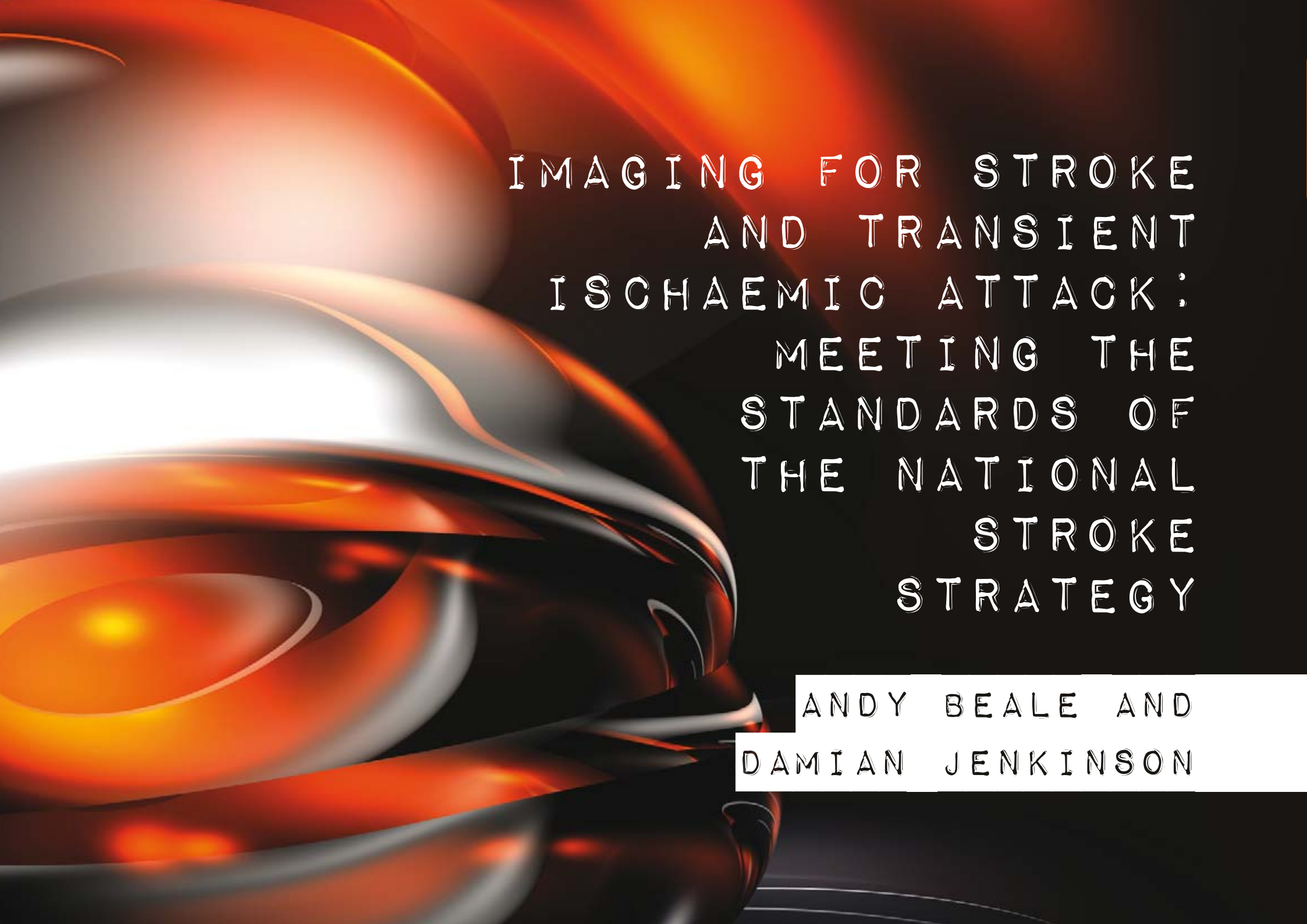

IMAGING FOR STROKE AND TRANSIENT ISCHAEMIC ATTACK: MEETING THE STANDARDS OF THE NATIONAL STROKE STRATEGY

ANDY BEALE AND DAMIAN JENKINSON

The National Stroke Strategy sets out clear targets for imaging services. Can they deliver?

INTRODUCTION

Stroke is the third biggest cause of death in the UK and the largest single cause of severe disability. Each year more than 110,000 people in England will suffer from a first stroke and a further 30,000 will suffer a recurrent stroke. Prior to stroke, one in five people experience a transient ischaemic attack (TIA), providing an opportunity for interventions to reduce vascular risk. The total cost of strokes to society is £8 billion per year, but less than 8 per cent of this is spent on initial medical diagnosis and management. The majority accrues from rehabilitation, nursing and indirect costs.

The National Stroke Strategy[1] in England, was launched in December 2007, and set a clear direction for the development of stroke services in England over the next 10 years. Much work has taken place to improve stroke services and the quality of care received by all who need it. There has been a recent concurrent public awareness campaign publicising the Act FAST criteria (Face, Arms, Speech and Time) for stroke and reinforcing the emphasis on 'time is brain'. Research quantifying cell damage estimates that two million brain cells are lost each minute in an acute middle cerebral artery infarct[2]. Therefore one of the biggest challenges set out in the strategy is the need for rapid imaging, both for TIA and stroke.

WHY BOTHER?

Previously, the management of cerebral ischaemia was based on optimal medical treatment. Now there are more specific treatment options for both strokes and TIAs. In strokes, thrombolysis has been shown to significantly improve outcomes if administered within three hours of onset[3] and shows moderate benefit if the window for treatment is extended to 4.5 hours[4]. In addition, intra-arterial fibrinolytic therapy can offer a moderate benefit in the 3-6 hour window[5]

FOR IMAGING DEPARTMENTS THERE ARE HUGE IMPLICATIONS

For TIAs, carotid recanalisation and, specifically, carotid endarterectomy (CEA), if performed early within two weeks of onset, can also improve outcome, leading to a reduction in subsequent debilitating stroke[6]. The College of Vascular Surgeons is working towards a 48-hour target from presentation to treatment (performing CEA) and has accepted that this needs to be implemented as soon as possible.

THE GUIDANCE

The emphasis on thrombolysis and CEA has led to the need for rapid access to imaging services as a key element in the gold standard service envisioned in the National Stroke Strategy. The chapter describing acute care of TIA and stroke, Time is Brain, contains two Quality Markers (QM) related specifically to brain imaging.

QM5 Assessment – referral to specialist (TIA and minor stroke)

Immediate referral for appropriately urgent specialist assessment and investigation is considered in all patients presenting with a recent TIA or minor stroke, using a system which identifies as urgent those with early risk of potentially preventable full stroke. To be assessed within 24 hours in high-risk cases; all other cases are assessed within seven days. (Using the ABCD2 criteria*). Provision to enable brain imaging within 24 hours and carotid intervention, echocardiography and ECG within 48 hours, where clinically indicated.

QM7 Urgent response (stroke)

All patients with suspected acute stroke are immediately transferred by ambulance to a receiving hospital providing hyper-acute stroke services (where a stroke triage system, expert clinical assessment, timely imaging and the ability to deliver intravenous thrombolysis treatment are available throughout the 24 hour period).

THE TARGETS (BY APRIL 2011)

1. 60% of high risk people (ABCD2 score 4 or more*) with TIA should be investigated and treated within 24 hours.
2. 50% of stroke patients to be scanned within one hour of hospital arrival.
3. 100% of stroke patients to be scanned within 24 hours of hospital arrival.

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* ABCD2 score is calculated using the patient's age (A); blood pressure (B); clinical features (C); duration of TIA symptoms (D); and presence of diabetes (2). Scores are between 0 and 7 points. Low risk = 0–3 points; moderate risk = 4–5 points; high-risk = 6–7 points.

These are ambitious goals, but will enable prevention of subsequent stroke in cases of TIA, and timely treatment in cases of stroke, reducing the risk of subsequent death and disability. In terms of changes to current service provision, the management of TIAs may represent a more significant challenge than the urgent response to stroke, particularly out of hours and at weekends.

IMAGING WORKLOAD IMPLICATIONS

In 2008, the Department of Health published 'Implementing the national stroke strategy, an imaging guide'[7]. This document, produced by a large number of stakeholders involved in imaging, estimated the expected workload for imaging departments. Within this document, there are calculations on the impact this would have by estimating the number of scans required for a given population. The figures given per 500,000 population are:

For TIAs:
- Approximately 30 patients a week presenting with TIAs.
- 50% will require brain imaging (66% within 24 hrs).
- 80% will require carotid imaging (66% within 24 hrs).

Thus anticipated imaging during the week, 12 MRI/MRA brain and 10 carotid imaging. During the weekend, three MRI/MRA brain and two carotid imaging.

For stroke:
- Approximately 25 patients a week presenting with strokes.
- Almost 100% will require brain imaging (50% within one hour).
- 10-20% of urgent cases will require additional imaging within 24 hours, eg MRI.

Thus anticipated imaging during the week, 15-17 brain CT and 3-4 MRI. During the weekend, 7-9 CTs with 1-2 a month requiring MRI.

This is a significant change from previous management. Although most stroke patients would have previously had some form of brain imaging (usually CT), the new guidelines require the scans within one hour, if urgent (50%), and within 24 hours otherwise. This requires departmental flexibility to accommodate scans at short notice. The implications in TIAs is perhaps more significant because most patients are not, at present, having MRI scans. This may add significantly more than 10 per cent to the workload of a district general hospital MRI scanner, compounding the already fully stretched national MRI capacity.

CURRENT PROVISION FOR TREATMENT

Thrombolysis is available in 88 per cent of acute trusts, (RCP audit May 2010) but only 50 per cent are 24/7[8]. Nevertheless, the availability of thrombolysis has increased significantly over the past two years.

CEA services are variable, with very few acute trusts offering a full 48-hour service. CEA within two weeks is achieved more frequently, but even this timescale is by no means universal. The Royal College of Vascular Surgeons remains committed to trying to improve CEA availability.

MONITORING

All primary care trusts will be expected to collect data relevant to imaging, which includes the following:

1. Treatment of higher risk individuals with TIA, defined by a score of 4 or more on the ABCD2 system[1]. They will be expected to provide data on the proportion of these patients who are scanned and treated within 24 hours of symptom onset.
2. For lower risk TIA, the same applies but for a seven day period.
3. Percentage of TIA patients with confirmed carotid stenosis receiving carotid intervention within 48 hours. Percentage of stroke patients scanned within one hour and 24 hours.

MOVING FORWARD, NEWER TECHNIQUES AND USAGE

Mechanical clot retrieval

Pilot trials suggest benefit from intravenous thrombolysis **and** endovascular mechanical clot retrieval/aspiration, using mechanical devices to dispose of large proximal clot burdens. This can be combined with the ability of lytics to initiate therapy early, or clean up smaller occlusions in distal arteries not accessible to mechanical attack[9]. At present, this is available only in major centres, usually performed by interventional neuroradiologists. Use of the 'hub and spoke model' and networking across stroke services should lead to an increase in the use of this technique.

CT perfusion scanning

CT perfusion is used widely already, although its role in the acute stroke setting is still under debate. Recent publicity in the United States has muddied the waters because patients having multiple CT brain perfusion scans suffered radiation burns and local hair loss. These reports reached the UK lay press. Nevertheless, the advantage in assessing objectively the 'penumbra' is, at present, being used particularly to assess those patients in whom the timing of onset of symptoms is unclear, eg the 'wake up strokes'. The additional information gained by the concurrent acquisition of a CT cerebral angiogram is helpful in some centres for assessment of arterial occlusion, prior to intra-arterial mechanical clot retrieval.

Carotid imaging

During working hours, most carotid imaging is performed using ultrasound, either by sonographers or vascular scientists. However, both CT angiography and MRA of the carotid arteries provide accurate assessment of carotid stenosis. There are issues regarding training both to acquire and to report CT and MRA images, but the availability of both these scans out of hours and at weekends may mean an increase in their usage. Indeed, this is already happening at a number of centres.

THERE IS VARIATION IN HOW EFFICIENTLY DEPARTMENTS USE EQUIPMENT

DISCUSSION

Changes in the way stroke and TIA services are being delivered are happening already. Targets have been set and there has already been a substantial improvement in access to timely imaging over the last few years.

For imaging departments there are huge implications. The impetus for TIAs imaging has led to an increase in workload and flexibility that requires a joined-up approach, particularly with vascular surgeons, to offer the complete service. Likewise, stroke physicians will need to ration their referrals for both MRI and carotid imaging because not all patients referred with TIA symptoms require imaging.

There are different strategies that imaging departments can introduce - and some already have - to help achieve these ambitious targets. Carotid arteries can be imaged with US, CT and MR angiography. Adapting to availability of these different modalities can facilitate a 24-hour turnaround. Training other staff, such as nurse practitioners, to provide carotid artery ultrasound screening has also been successfully trialled in Exeter[10]. Including stroke and TIA imaging as part of seven day working can facilitate the development of business cases and designing workflow. MRI brain imaging capacity can be created by providing 'short scans'. There is no evidence of significant quality loss but patient throughput is increased.

In the urgent stroke setting, training more radiographers to perform CT heads is being encouraged by the Society and College of Radiographers and many centres have implemented this already. Reducing the time between arrival in the accident and emergency department and CT is vital. Paramedics given access for direct referral have reduced time to scan and the concern that there would be subsequent unnecessary examinations has not materialised. Cascade bleep systems, as used in the cardiac arrest scenario, can include the CT radiographer, who can have the scanner ready to receive the thrombolysis patient.

Stroke and TIA imaging should, however, not be seen in isolation and there are numerous other pressures on departments, including recent emphasis on cancer targets and seven day working, to name but two. However, there is a wide variation in how efficiently different departments use their equipment and reviewing all aspects of workflow and patient throughput is vital[10]. The claims that all departments are working to 'full capacity' is not supported by analysis and the National Audit Office is currently linvestigating the utilisation of high cost equipment, including MRI, CT and Linacs. They will be reporting in the spring of 2011.

CONCLUSION

The days of passive management in stroke and TIAs are over. Imaging departments cannot rest easy and must engage in the concept of 'Time is Brain' to do their part in improving the outcome of these conditions.

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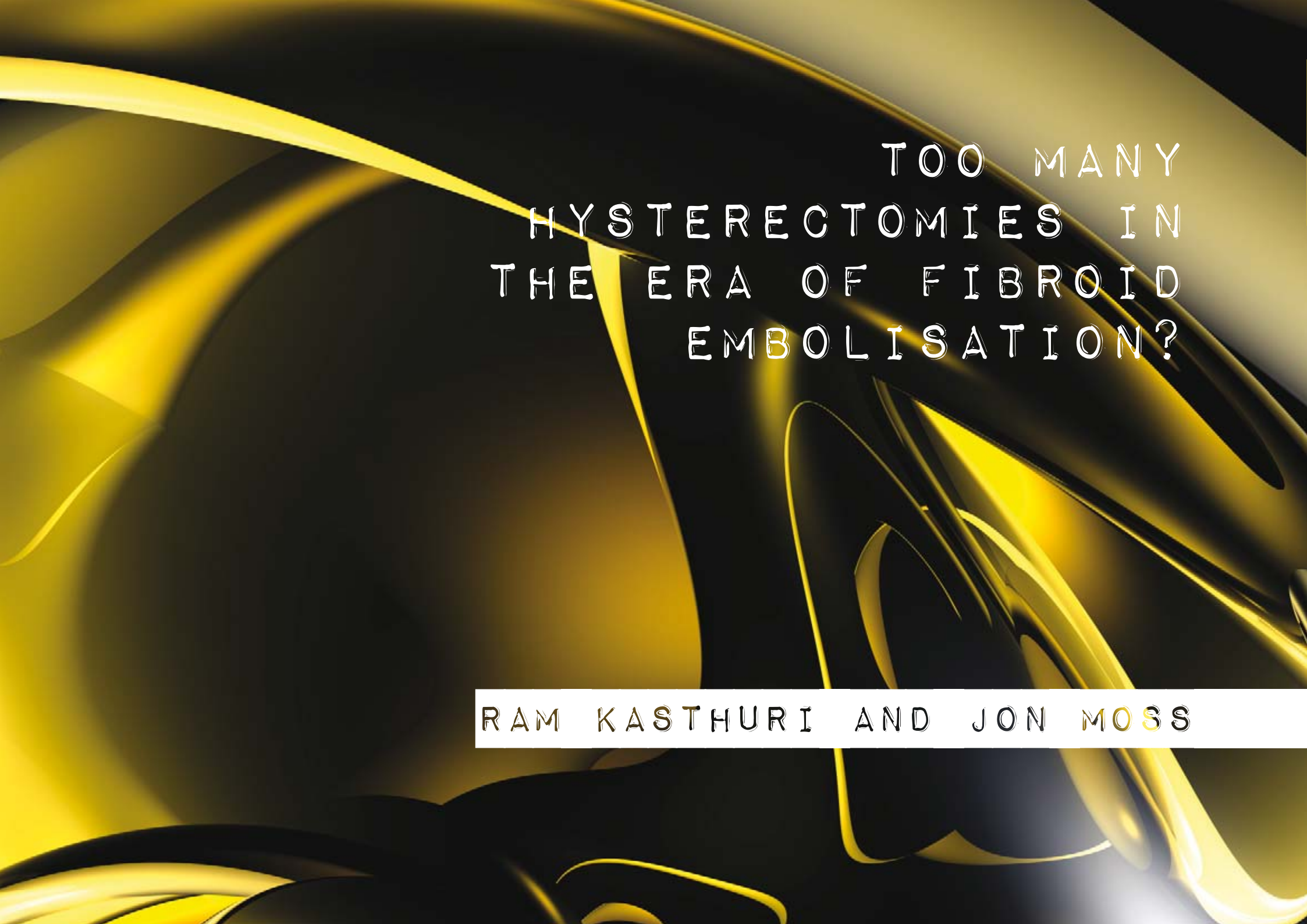

TOO MANY HYSTERECTOMIES IN THE ERA OF FIBROID EMBOLISATION?

RAM KASTHURI AND JON MOSS

The role of uterine artery embolisation in the management of symptomatic fibroids is established but not always readily available. What are the factors behind this?

Uterine fibroids or leiomyomata are the most common tumours of the female reproductive system[1]. The overall incidence is approximated at between 20 -70 per cent depending on age/menstrual status and race[2]. Whilst fibroids are benign and asymptomatic in the majority, they can cause debilitating symptoms, including heavy and painful periods, and pressure symptoms[3,4].

Pharmacological management is usually the first line treatment with anti-inflammatory hormone therapy or gonadotrophin releasing hormone agonists[5]. Depending on the type of fibroid and individual patient circumstances, more invasive techniques such as uterine artery embolisation, or surgical options including myomectomy or hysterectomy, may be considered.

UTERINE ARTERY EMBOLISATION – WHERE WE ARE NOW

Uterine artery embolisation is an interventional radiological technique involving selective cannulation of both the left and right uterine arteries in turn, and embolisation, usually using particles. This technique was first reported as an alternative to surgical treatment in 1991 by Ravina et al followed by a series by the same group in 1995[6,7]. Over the last 15 years, more than 100,000 procedures have been performed in Europe and the USA, with a number of these being part of registries and randomised controlled trials (RCTs).

Initial evidence was from single centre cohorts, but were followed by at least four multicentre RCTs published between 2003 and 2008[8-11]. The comparison arms were hysterectomy[8,9], myomectomy[10] and either[11]. Different primary end points were also used in these four RCTs.

A prospective fibroid registry from the USA, whilst voluntary and without a control cohort, provided useful data on a large number (n=3160) of fibroid embolisations. Similarly, the UK HOPEFUL[12] study involves large numbers (n=1108), but is a retrospective comparison of UAE with hysterectomy in a matched cohort. Despite all the above variations, the results are more or less comparable across the range of variably powered and designed studies. In summary, UAE is comparable to hysterectomy with regard to quality of life (QoL); the hospital stay and recovery time is shorter with UAE; and the cost-effectiveness at one year favours UAE. On the other hand, symptom control following UAE does not match hysterectomy, with approximately 10 per cent of UAE patients needing a second procedure for symptom control.

Based on current literature at the time, in 2000 the joint working party of the Royal College of Radiologists and the Royal College of Obstetricians and Gynaecologists issued recommendations on the use of uterine artery embolisation in the management of fibroids. These were updated in June 2009 [13]. The National Institute of Health and Clinical Excellence (NICE) has also issued full guidance to the NHS in England, Wales and Scotland on UAE, which was updated just at the end of last year[14]. In addition, UAE figures in the NICE guidelines for the management of heavy menstrual bleeding[15].

WHY ARE MORE HYSTERECTOMIES BEING DONE?

Hysterectomies are the most common major gynaecological surgery worldwide. Although the numbers of hysterectomies for fibroids have decreased as compared to a decade ago, there are more hysterectomies being done worldwide as compared to all other non-pharmacological techniques.

In 2005/2006, there were 38,631 hysterectomies performed in NHS hospitals in England & Wales[16] and approximately 30 per cent of these for benign disease. Fibroids constituted the majority of these benign conditions.

The patient

The majority of patients who consider non-pharmacological treatment for symptomatic fibroids are older and are likely to have completed their family. Therefore, in this patient group, persistent symptom resolution is more a priority than retention of the uterus. Also, the process of investigation, initial medical management with hormones and/or gonadotrophin releasing hormone (GnRH) analogues, delays resolution. These patients

PATIENTS NEED TO CONSIDER UAE AS SAFE AND EFFICIENT

are keen to be free of their very troublesome symptoms. So, in comparison with the prospect of going through initial imaging, followed by the embolisation procedure, and follow up imaging with a one in 10 potential of a further procedure, a hysterectomy, despite being highly invasive and radical, is preferred by a number of patients. Further, hysterectomy is associated with a high rate of satisfaction and is likely to eliminate menstrual symptoms in virtually all the patients. Even in patients with early post operative complications, the long term satisfaction rate is very high[17].

For patients not keen to retain their uteri, hysterectomy as a treatment option, with its high efficacy, readily available expertise to perform the procedure and high satisfaction rate with time-tested results, makes consideration of any other alternative very academic.

In order for a patient to prefer one procedure over another, there must be a choice. There have certainly been cases in the past where the patients have not been informed of uterine artery embolisation as an option. There have also been cases where the clinician mentions the procedure more for completeness, neither giving the patient facts nor any information about local availability. Fortunately, such inappropriate consulting is occurring less frequently now, especially after publication of the recent National Institute for Health and Clinical Excellence (NICE) guidelines and the joint working party report.

The clinician

The vast majority of patients with symptomatic fibroids are usually referred by their general practitioner to a gynaecologist for further management. The gynaecologist would usually exhaust pharmacological options prior to considering interventional procedures. For women with large fibroids (> 3cms) causing symptoms of heavy menstrual bleeding, as well as other symptoms such as dysmenorrhoea or pressure symptoms, UAE or surgery can be considered[15]. This is the recommended generic management guideline from NICE across the range of procedures for symptomatic fibroids. Sub-group indications for the different procedures are not specified. The guidelines also recommend that any decision should be reached only after a detailed discussion regarding all treatment options has been had with the patient. Therefore, the consulting clinician plays a significant role in the choice of the treatment procedure.

To be able to discuss the available treatment options it is imperative that the gynaecologist has comprehensive knowledge of UAE including the practical patient issues, technical aspects and potential complications. The clinician should also be up-to-date on the current literature. This, in clinical practice, can be very difficult. As a result, there may be an unconscious clinician bias towards the surgical techniques. However, this problem can be overcome by interventional radiology consultations.

New procedure syndrome

Uterine artery embolisation is still considered by many as a new procedure. Although clearly a safe procedure with proven efficacy in the short to medium term, long term follow-up data from the trials and registries are outstanding.

In the NHS, any new procedure or service usually requires a business case to establish not only the safety and efficacy of the procedure, but also its cost effectiveness[18]. Making a robust case to start a new procedure to treat a condition with well established treatment alternatives has, in the past, been difficult. This is particularly true as the service involves incurring extra expenditure to already overstretched radiology departments. This may, at times, inhibit the development of a new service or procedure.

Also, most interventional radiologists currently performing UAE have developed this skill as consultants rather than as trainees and there certainly is a learning curve involved. This requires enthusiasm, be it visiting another centre performing these procedures, or being mentored at one`s own centre by an expert.

Availability of local skilled expertise is another factor. Whilst the majority of UK hospitals have access to interventional radiology, this may not be local. Patients therefore may have to be referred to another centre. This introduces another potential disadvantage when the patient considers her options.

All the above factors are significant, but the most important factor is education and awareness of the procedure. There is still a minority of clinicians who claim not to believe in the role of UAE in the management of fibroids. In the face of overwhelming evidence, this can only be due to ignorance or laggardness. Consequently, there are a less than par number of UAEs performed for symptomatic fibroids.

WHERE DO WE GO FROM HERE?

The role of uterine artery embolisation in the management of symptomatic fibroids is now established but certain key areas will determine and secure the future of this treatment:

Clinical sub-specialty

Patients deemed suitable for the procedure are referred by the clinician to interventional radiology. In a number of units, there is a lack of direct radiology involvement both before and after the procedure. Therefore the interventional radiologist becomes a technician rather than a clinical practitioner. This non-clinical approach means that the interventional radiologist carries out an invasive procedure on a patient without prior personal assessment of the patient. This is a major drawback and should be discouraged.

Ideally, patients should first be seen in an interventional radiology outpatient clinic[19]. During this consultation, the patient should be assessed by the interventional radiologist regarding the appropriate symptoms being treated; imaging reviewed; and the procedure should be discussed in detail. This includes the alternatives, practical implications and the possible complications. There should also be robust post procedure follow up by the interventional radiologist. It is our practice to follow up patients in the interventional radiology out-patient clinic at six weeks, six months and 12 months following the

procedure. The first follow-up visit is to look for post procedure complications, and the subsequent ones to check on symptom benefit and late complications.

The recent recognition of interventional radiology as an official sub-specialty by the postgraduate medical education and training board (PMETB) further contributes to the process of development of the clinical interventional radiologist.

Research

There are still a number of questions in the management of symptomatic fibroids and, more specifically, within interventional radiology:

- How does UAE compare to myomectomy in the same patient group? This is a key question because both techniques are uterus sparing. An RCT from Mara et al[10] randomised patients to either UAE or myomectomy, and they have reported mid term results. Their numbers, however, are small and this is still an unanswered question.
- Is there an ideal embolic agent?
- Is there an ideal particle size?
- Is it possible to predict fibroid shrinkage on pre-procedure imaging?
- Is there a sub-clinical effect of UAE on fertility?

The long-term follow-up data from the clinical trials, as mentioned before, are outstanding. Research is crucial in the continued development of the technique and for answering these important questions. Equally, other minimally invasive alternatives such as magnetic resonance guided focussed ultrasound treatment [20] and magnetic resonance guided laser ablation[21] are under development and are showing promising results.

Training

The ready availability of local expertise in UAE is variable across the United Kingdom and this is an important factor from both the patient's and the referrer's perspective. The local UAE service should also be staffed with skilled and competent personnel. Training of interventional radiologists in the procedure is another key factor. The training should not be restricted to technical competence, but also include patient assessment, both clinical and radiological, as well as follow-up.

Guidance on appropriate training in the various aspects of UAE features both in the Royal College of Radiologists` new curriculum[22] and the Interventional Radiology syllabus[23], as recommended by the Cardiovascular and Interventional Radiological Society of Europe (CIRSE). These measures help standardise training, thus helping to ensure delivery of a quality service.

Education

Educating patients, clinicians and even the general public will help significantly in developing a greater understanding of the procedure, thus enhancing its profile and generating greater public acceptance. Patients need to consider UEA as a safe and efficient treatment procedure for fibroids.

The clinicians - both primary care and secondary referrers - need working knowledge of the indications, the current literature, the practicalities involved for the patient, and the potential complications. This process should also include non interventional radiologists who are sometimes consulted regarding treatment of fibroids.

Uterine artery embolisation is perceived by the general public as an experimental procedure restricted to a few specialised centres. During consultations, patients often enquire if the procedure is experimental. Any misconceptions must be overcome and education is the key. A robust patient information leaflet is essential and should be disseminated to general practices and other appropriate public areas. The internet is another powerful tool in educating the public, but it can equally be a deterrent with some websites giving wrong or inaccurate information. Arguably, another effective method of information dissemination is the patient herself. A good overall experience with good symptom benefit can result in a 'word of mouth' type education for the wider public. Any way of enhancing profile is good for the procedure.

CONCLUSION

Uterine artery embolisation should be considered in patients with symptomatic fibroids who desire to retain their uterus, irrespective of their age. Continued research and technological developments will ensure the procedure evolves and gains more widespread acceptance and popularity. In terms of patient welfare and cost effectiveness in today's patient-focused healthcare environment, the benefits of UAE are irrefutable, and it is no longer acceptable to perform hysterectomies because of a lack of local expertise and/or ignorance.

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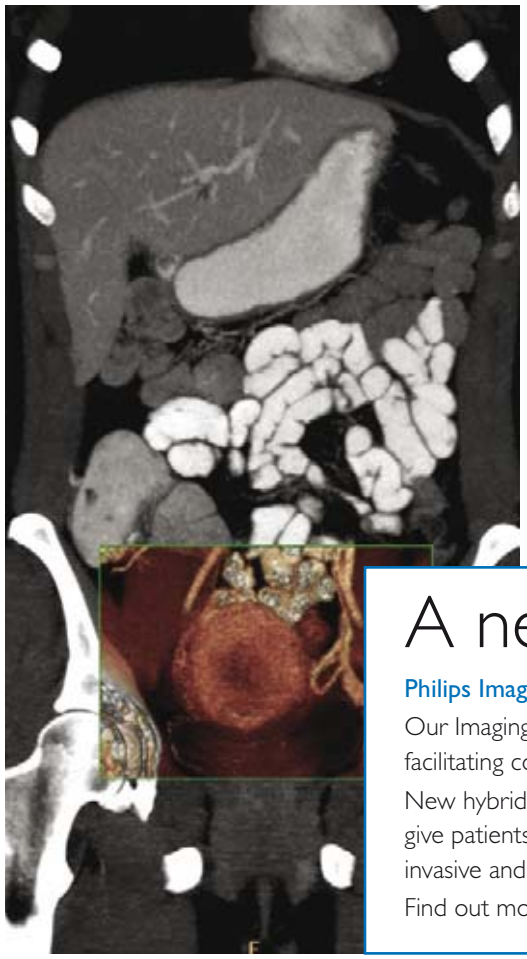

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A PICTURE OF THE FUTURE: CARDIAC CT

JOHN CURTIN

How will new cardiac guidelines affect CT cardiac angiography services?

INTRODUCTION

Cardiac computed tomography (CT) has evolved at extraordinary speed from little more than an interesting concept a decade ago to a mature diagnostic tool today. Advances in CT technology and robust evidence from a multitude of research studies have led to the development of guidelines and recommendations for its appropriate use by organisations such as the American College of Cardiology[1,2] and the National Institute for Health and Clinical Excellence[3].

Now it is a mainstream investigation for patients with known or suspected cardiac pathologies. Over the next few years it will become an everyday procedure in most United Kingdom hospitals, part of the routine workload of CT radiographers. It is the most complex of all of the CT investigations we currently perform, making it a challenging, fascinating, and rewarding endeavour.

TECHNOLOGY

The earliest contribution of CT to cardiac imaging dates back to the early 1980s in the shape of electron beam CT (EBCT) scanners, which could effectively freeze cardiac motion because of the great rapidity with which they acquired an image – their very high 'temporal resolution'. They found a niche in the evaluation of coronary artery calcification scoring in the 1990s[4] but their spatial resolution was inadequate for coronary angiography. Their high cost, compared to conventional CT scanners, has always limited the number of EBCT scanners.

The era of CT coronary angiography (CTCA) really began with the advent of 4-slice multislice CT scanners in 1998, with research papers on its use for cardiac imaging appearing soon after[5]. Since the turn of the century, and in keeping with Moore's Law, multislice scanners have 'morphed' from 4-slice to 16-slice to 32-slice to 64-slice machines and beyond, and image quality has improved apace. These scanners have the necessary speed to image the contrast-enhanced coronary arteries in a single breath hold (figure 1). Currently, 128-slice scanners are commonplace, while we also have dual-source scanners that increase temporal resolution by a factor of two, and even a 320-slice scanner, which can image the whole heart in end-diastole of a single heartbeat.

CTCA is, however, still inferior to conventional catheter angiography in both its spatial and its temporal resolution. The spatial resolution of current CT scanners is such that each pixel represents a voxel measuring approximately 0.35mm x 0.35mm x 0.35mm, while conventional angiography pixels measure approximately 0.16mm x 0.16mm.

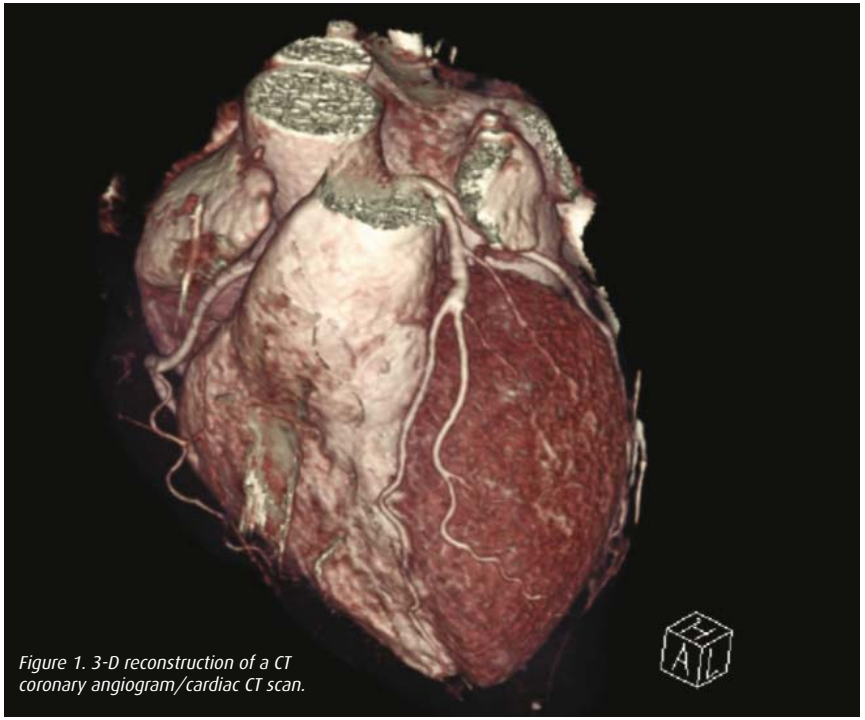


Figure 1. 3-D reconstruction of a CT coronary angiogram/cardiac CT scan.

IT IS COMPLEX AND DEMANDING

Given the small size of the coronary arteries - the proximal coronaries usually measure 2mm to 5mm in diameter[6] - this is a significant disadvantage, particularly for the smaller distal and branch arteries.

The temporal resolution of conventional catheter angiography is in the region of 30ms, while most CT scanners have a temporal resolution of approximately 150ms. (This can be reduced to less than 100ms by using a low-pitch spiral acquisition and multisegment reconstruction[7], and dual source CT scanners have a temporal resolution of approximately 75ms.) There is a greater potential for motion artefact with CT which can result in blurred, non-diagnostic images. Another significant problem for CT is that it does not depict accurately calcified plaques within the arterial wall. As a consequence

of partial volume artefact and blooming artefact, it overestimates the size of calcified plaques and thus the degree of stenosis caused by such plaques[8].

Given these limitations, why should we use CT at all for imaging of the heart and coronary vessels? The answer is that a test which is less than perfect may yet be good enough to answer a particular question in a particular clinical context. CTCA can be definitively diagnostic in certain situations. It has the general advantages over conventional angiography of being less costly, of demonstrating plaque density and plaques not visible to conventional angiography. Because the contrast is given intravenously, arterial puncture and intra-arterial catheters are not required.

ECG-GATING AND HEART RATE CONTROL

Successful cardiac CT requires ECG-gating and a slow steady heart rate. At a pulse rate of 60bpm, each cardiac cycle lasts one second. A 320 slice CT scanner, or a dual-source 128-slice CT scanner, can image the entire heart in about 0.3 seconds, with a temporal resolution of 150ms and 75ms respectively. This sounds impressively fast, but it constitutes a large fraction of even this rather leisurely cardiac cycle. The right coronary artery, for example, can move up to 4cm during this one second[9].

The heart, however, does not move at a uniform steady pace over the cardiac cycle; it moves rapidly in systole and is relatively static during diastole. So, for example, to obtain motion-free images of the coronary arteries with a 320-slice scanner, it is generally best to acquire the images during diastole rather than systole. In fact, most CT scanners cannot scan through the heart so quickly, instead acquiring the data in aliquots over multiple heartbeats. In either case, we have to have co-ordinate the data we acquire to the cardiac cycle. For this we connect ECG leads to the patient which feed the ECG trace to the CT scanner, enabling the scanner to synchronise the acquisition with the patient's cardiac cycle. This is ECG-gating: an absolute necessity for cardiac CT.

Cardiac CT can also provide functional information. Here, data are acquired over the whole cardiac cycle. The resulting slices are ordered according to the synchronous ECG data, each of which corresponds to a snapshot of the heart at a particular point in the cardiac cycle. These snapshots can then be viewed as a video loop to look for outflow tract obstruction or wall-motion abnormalities, for example, or to measure ventricular volumes and ejection fractions. Another aspect of function that can be investigated with CT is myocardial perfusion and delayed enhancement in suspected ischaemic heart disease, though research in this area is in its infancy.

ECG-gating can be of two basic types: prospective, in which the x-ray beam is activated during a short predetermined portion of the cardiac cycle, for example between 65 and 75 per cent of the time from the start of one cardiac cycle to the start of the next; and retrospective, when the patient is irradiated continually and afterwards the data collected are matched to the ECG-trace over the period of the acquisition. Both types of ECG-gating can also be mixed. For example, we can modulate the intensity of the x-ray beam in a retrospective acquisition so that it is maximal in diastole and very low for the remainder of the cardiac cycle (figure 2).

Good quality motion-free images require a slow steady heart rate, so that the length of diastole is long enough for the relatively sluggish CT scanner to collect the data while the heart is at rest. For single source scanners, the heart rate should ideally be less than 65bpm. For dual source scanners, a heart rate up to 75bpm is acceptable. In order to achieve these heart rates, some patients require beta-blocking drugs, either orally an hour before the scan, or intravenously in the scan room[10]. Nitroglycerin is used commonly to dilate the coronary arteries, increasing the diameter of the proximal coronary arteries by a mean of 0.5mm, compensating in part for the limited spatial resolution of CT for such small vessels[10,11].

THE CURSE OF CHOICE

Politicians from the major parties have, of late, been convinced that when it comes to health care what patients/clients/customers desperately want is 'choice'. Whether they will succeed in persuading us that we crave this nebulous concept remains to be seen. Choice, we know, is not an unalloyed good, as it is wont to create anxiety and confusion.

Consider the cardiologist in her outpatient clinic faced with a patient who has, no doubt, appeared there by an unfathomable synergy of freewill and government enforced choice, with recent onset stable chest pain, possibly cardiac in origin. She has a bewildering array of investigations at her disposal: exercise ECG, catheter angiography, echocardiography, stress echocardiography, stress-MRI, delayed enhancement MRI, CTCA, MIBI scan, intravascular ultrasound, PET and, soon perhaps, stress CT. Happily, she can simplify this list into two broad categories: 'anatomical' tests which show the coronary artery lumen, and 'functional' tests which demonstrate myocardial ischaemia.

A powerful argument in favour of using a functional test first is that a coronary artery stenosis, no matter how severe, is probably not worth treating unless it is causing myocardial ischaemia[12]. The genie of choice, however, is not so easily grasped and bottled because there are other factors to consider. These include sensitivity and specificity of the tests over the whole range of the pre-test probability of disease, as well as the costs, risks, and ancillary benefits of each test.

When should she choose CT?

INDICATIONS FOR CARDIAC CT

Most of the research on cardiac CT relates to its use in suspected coronary artery disease (CAD). Like catheter angiography, CTCA is an anatomical rather than a functional test, demonstrating the lumina of the coronary arteries. It is more sensitive for the detection of small plaques and, unlike catheter angiography, it also provides information on the wall of the arteries and the density of any atheromatous plaques (figures 3 and 4). Pragmatically,

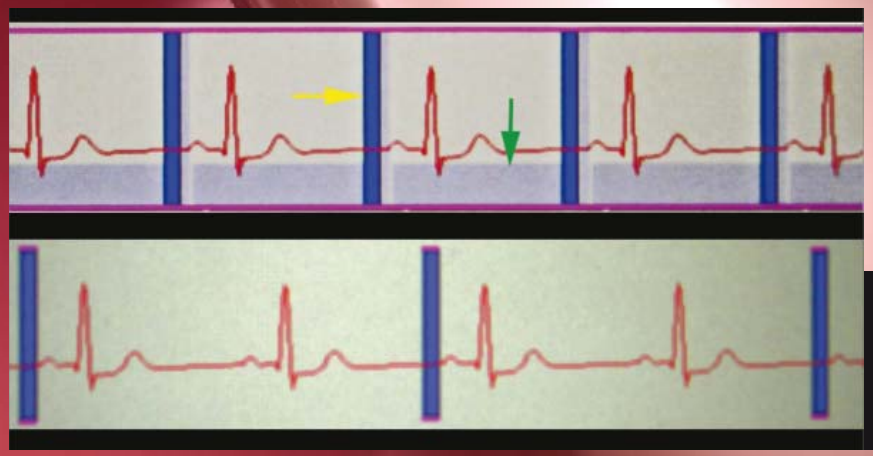


Figure 2. ECG gating: The upper image demonstrates modulated retrospective ECG gating. The vertical blue columns (yellow arrow) indicate when the full mAs is being delivered, in this case in diastole, while the fainter light blue bars (green arrow) represent the reduced dose (20%) delivered in between the full dose periods. The lower image demonstrates prospective ECG gating in 'step-and-shoot' mode. An axial scan acquires a volume corresponding to the detector width in the z-axis, then the table moves to the next position and another volume is acquired in the same phase of the cardiac cycle, and so on until the entire heart has been covered. Usually three to four acquisitions are required.

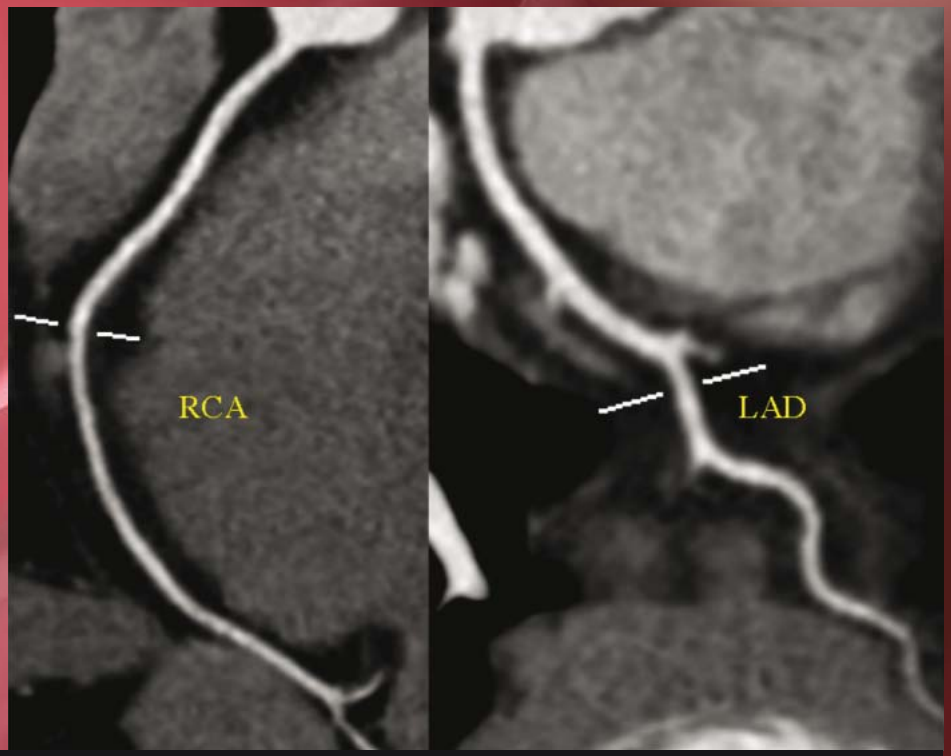


Figure 3. Curved multiplanar reconstruction of the right coronary artery (RCA - left image) and left anterior descending artery (LAD – right image). Both arteries appear entirely normal. The white lines delineate the centre of rotation of these curved MPRs.

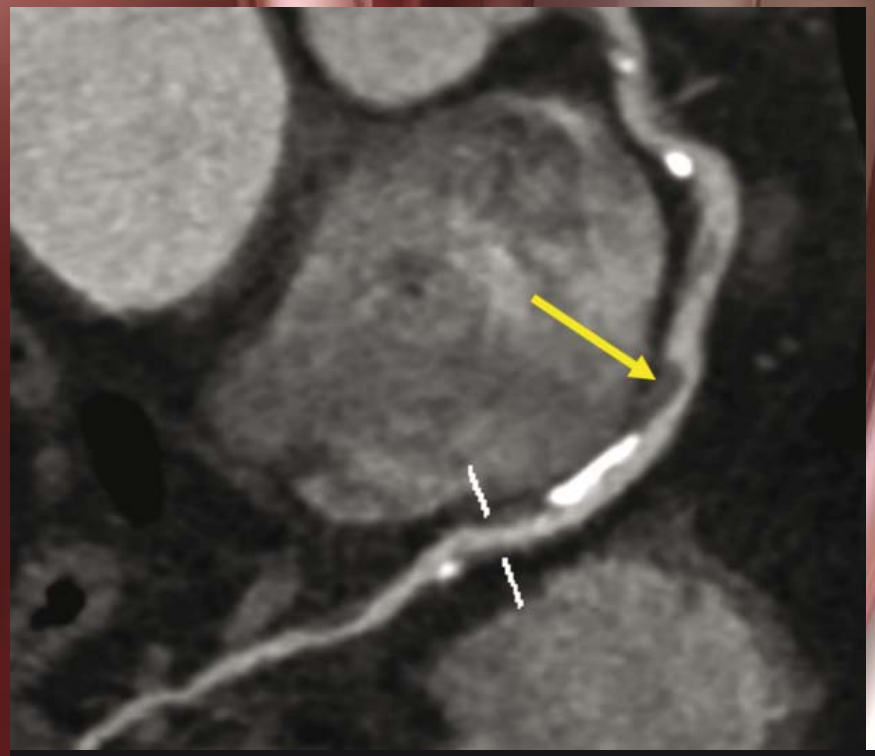


Figure 4. Curved MPR of the right coronary artery demonstrating multiple atheromatous plaques, some calcified, some not. The arrow points to a large soft plaque causing approximately 70 per cent stenosis.

however, it is clear that catheter angiography has a much longer pedigree and a much larger evidence base for clinical decision making founded on its results than does CTCA. So what role, if any, can CTCA play in the investigation of patients with suspected CAD?

One of the strengths of CTCA is its very high negative predictive value. If it does not demonstrate any significant stenosis, it is right almost 100 per cent of the time and the patient is very unlikely to have an adverse coronary event any time in the near future[13]. One of its weaknesses is that it tends to overestimate the degree of stenosis caused by large calcified plaques. As a patient's pre-test probability of CAD increases, the likelihood that the patient will have extensive calcified atheromatous plaques also increases. The utility of CTCA decreases, not for the detection of coronary artery plaques, but for quantifying the severity of any resultant stenosis. A significant proportion of these patients may also require angioplasty or stent insertion, making catheter angiography a more logical first-line investigation.

The 2010 National Institute for Health and Clinical Excellence (NICE) guidelines on 'Chest pain of recent onset: assessment and diagnosis of recent onset chest pain or discomfort of suspected cardiac origin'[3] are mindful of these facts. They recommend that people presenting with recent onset of stable chest pain who have a 10-30 per cent likelihood of having CAD should have a CT coronary artery calcification score. If this (Agatston score) falls between 1 and 400, they should then have a CT coronary angiogram. Clearly, they have chosen this group because the majority are likely to have normal or mildly abnormal coronary arteries. CTCA will confirm that most of these patients do not have significant disease and require no further investigation, while identifying the small proportion that do.

In practice, CTCA may be used more widely in patients with CAD. Recent guidelines from the USA[2] considered 93 clinical scenarios and decided that it was appropriate to perform CTCA for 35 of these indications, most of which relate to possible CAD. Direct comparison between these recommendations and those of NICE are difficult because they use different thresholds of pre-test probability to trigger different investigations. Broadly, the American recommendations suggest that CTCA is a reasonable test in a wider range of patients, including those in the 30-60 per cent pre-test probability range. NICE recommends functional imaging, such as a nuclear medicine myocardial perfusion scan, as the best first-line test for this scenario.

For patients with acute chest pain, NICE[3] does not see any role for CTCA. The USA guidelines[2] suggest that it may be appropriate for selected patients presenting with acute chest pain, who have a low or intermediate pre-test probability of CAD. The main benefits in this group are lower investigation costs and reduced admission rates[14,15,16].

A related postulated use for ECG-gated CT is the 'triple rule-out CT'. This is when clinicians find themselves uncertain whether a patient has myocardial ischaemia, pulmonary embolism (PE), or aortic dissection[17]. No doubt this clinical dilemma does occasionally arise in practice. We have all seen aortic dissection in patients being scanned for possible

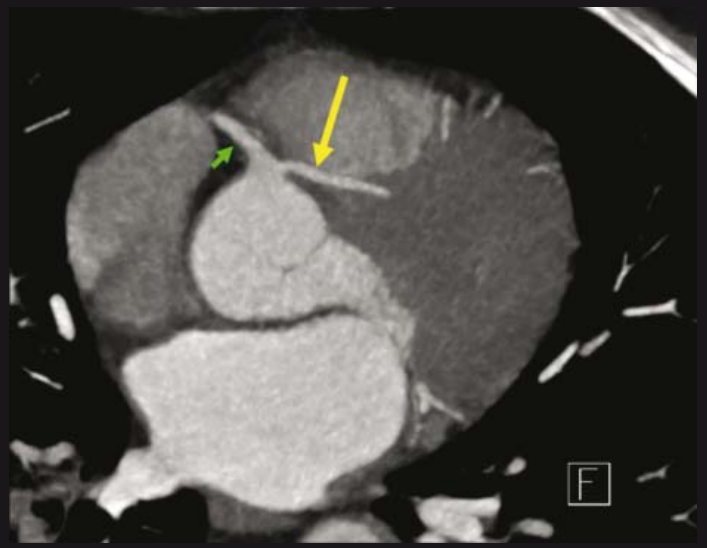
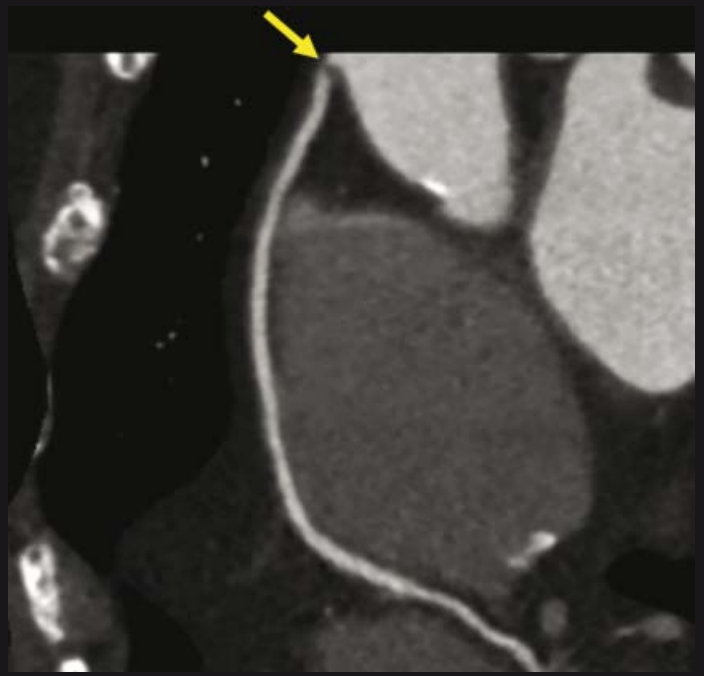


Figure 5. Maximum intensity projection image from a CTCA demonstrating the left anterior descending artery (yellow arrow) arising anomalously from the right coronary artery (green arrow).

Figure 6. Curved MPR from a CTCA demonstrating a severe stenosis in a vein graft to the right coronary artery, close to its origin from the ascending aorta (arrow).



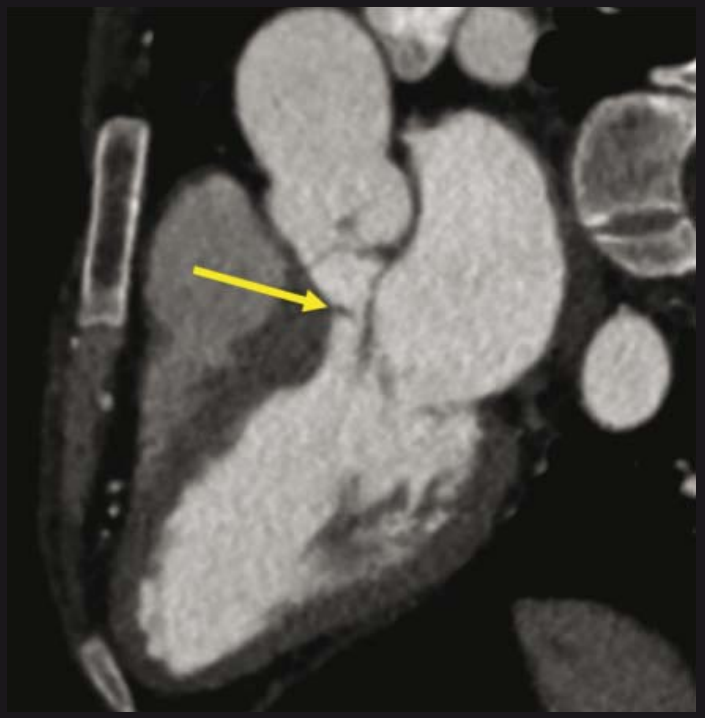


Figure 7. Oblique MPR from a CTCA demonstrating a membrane (arrow) projecting into the left ventricular outflow tract, which was causing significant stenosis.

WHAT ROLE CAN CTCA PLAY IN SUSPECTED CAD?

PE, and vice-versa. Indeed, these pathologies can occur together. However, if a 'triple rule-out' service is offered, arguably, it will be requested more often than strictly warranted. This is in accordance with the unspoken and doubtful premise that equates more testing with better care, which is used as an alternative to proper clinical assessment[18].

CTCA has an undisputed role in the imaging of patients who have anomalous coronary arteries (figure 5). It has very high sensitivity and specificity for graft stenosis or occlusion in patients who have a coronary artery bypass graft[2,19,20] (figure 6). It is less accurate for evaluation of the native coronary arteries distal to the anastomosis and for evaluation of the anastomosis itself[21]. It can be used for assessment of the coronary arteries prior to non-coronary cardiac surgery.

Cardiac CT is good for the investigation of complex adult congenital heart disease when other investigations such as echocardiography and MRI are contraindicated or inadequate (figure 7). Not only does it demonstrate clearly the complex anatomy in these patients, but can also provide information on their ventricular function[22].

There are multiple other uses and potential uses for cardiac CT including: the assessment of valve abnormalities[23], left atrial and pulmonary venous imaging to plan radiofrequency ablation[24], evaluation of cardiac masses, monitoring the evolution of atheromatous plaques[25], and myocardial perfusion and delayed enhancement imaging[26].

RADIATION DOSE

The radiation burden associated with CTCA has been the subject of intense interest over the past five years. In part because of raised awareness of the large and increasing radiation dose which CT scanners expose the population to - and the attendant risk of this radiation - and, in part, because the radiation dose delivered by CTCA can be very high: up to 25mSv[27]. Unmodulated retrospective ECG-gated CTCA in particular, is a very high dose examination. Modulated retrospective ECG-gated CTCA, where the maximal radiation dose is only used over a small portion of the cardiac cycle, reducing to 20 per cent or less for the rest, gives significantly lower doses in the region of 7 to 14mSv.

Prospective ECG-gating leads to yet lower dose examinations. Most commonly, multiple non-helical scans are obtained, the table moving between each 'slice' (usually a 4cm volume) to cover the desired z-axis range, usually three or four slightly overlapped volumes for a typical heart. This yields doses in the region of 1mSv to 4.5mSv[27,28], which compare favourably with the dose from conventional coronary angiography (mean 7mSv) and nuclear medicine stress tests (eg ^{99}mTc-sestamibi mean 9mSv) [29,30]. For selected patients, a dual-source 128-slice scanner can also scan the entire heart in a single heartbeat with doses in the region of just 1mSv[31].

It is anticipated that new iterative reconstruction algorithms may produce diagnostic images using less radiation than filtered back projection algorithms[32]. Multiphase

datasets, which give a better chance of obtaining motion-free images of all segments of the coronary arteries and which can be used to assess function , are not the sole preserve of retrospectively ECG-gated acquisitions. They can also be acquired prospectively, potentially at lower dose[33].

Despite the encouraging downward trend in radiation dose for CTCA, there are risks at even low doses - greater for younger patients, particularly females - and we must be sure that the expected benefits of the examination outweigh the risks.

SERVICE REQUIREMENTS

A 64-slice scanner with cardiac software, a dual-headed CT-injector, radiographers who understand and are familiar with cardiac CT, radiologists and/or cardiologists who have completed a Level 2 course in cardiac imaging, and appropriate sessional time for performing and reporting scans, are all essential[34,35]. The website of the British Society of Cardiovascular Imaging[36] is a good resource for those new to cardiac imaging and lists appropriate courses for radiographers, radiologists, and cardiologists.

Patients must, of course, be informed in advance of the details of the procedure. A nurse who can ascertain the patient's pulse rate and blood pressure, perform an ECG, determine what medications the patient is taking, assess for contra-indications to beta-blockers, nitroglycerin, and contrast, and administer beta-blockers if necessary, can be enormously helpful.

Good communication between referrers and those performing the examinations ensures that referrers are aware of the strengths and limitations of the technique and that they refer appropriately. It also ensures that the imaging team receives valuable feedback. Historically, communication between cardiology and radiology departments has been limited because staff in cardiology departments have performed the imaging that is most germane for their patients, namely echocardiography and catheter angiography. With increasing numbers of patients having cardiac MRI, CT, and nuclear medicine scans, which are performed by radiographers and often reported by radiologists, there is a compelling argument for regular clinical meetings between these departments.

THE FUTURE OF CARDIAC CT

ECG-gated multislice CT is now an established non-invasive technique for investigating suspected coronary artery disease and a number of other cardiac pathologies. Given the recent NICE recommendation on using CTCA for a subset of patients presenting with chest pain, we are on the threshold of new era in which cardiac CT will become a standard investigation to be provided by all CT departments in the UK. It is, however, complex and demanding. To replicate the accuracy achieved under research conditions in centres of excellence, we need to be scrupulous in patient selection, patient preparation, acquisition technique, minimisation of radiation dose, post-processing, interpretation, follow-up/feedback, and all aspects of quality control.

Further developments in CT technology are likely to bring better temporal and spatial resolution, reducing artefacts, and improving anatomical diagnostic accuracy. The most interesting and exciting development of cardiac CT, however, is its potential for functional imaging, particularly myocardial perfusion and delayed enhancement imaging in the setting of CAD[26]. If it fulfils its promise in this arena, it will be the only test in the cardiologists' armamentarium which can demonstrate both coronary artery disease and its functional significance in a single convenient 'one-stop' assessment. This combined intelligence is essential for appropriate patient management and will make cardiac CT an even more cost-effective, useful and sought-after investigation.

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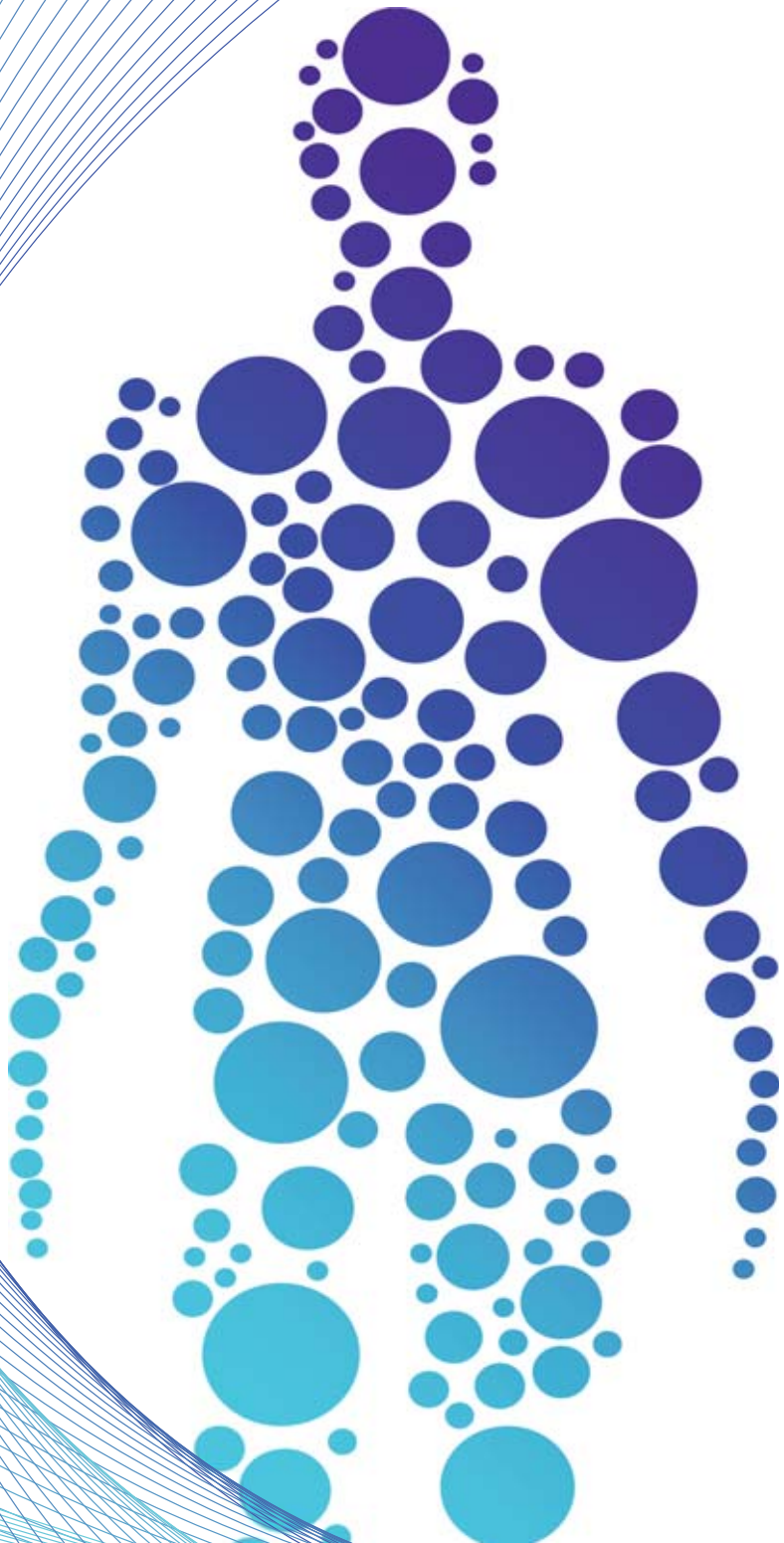

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