A guide to modern radiotherapy

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Summary

This document provides up to date information for patients on radiotherapy. Radiotherapy is the use of radiation to damage and kill diseased cells. Its main use is found in cancer treatment where it can be used on its own, or as part of a wider treatment of the cancer which might also involve surgery or chemotherapy.

What is radiotherapy?

Radiotherapy is the use of radiation to damage and kill diseased cells. Its main use is found in cancer treatment where it can be used on its own, or as part of a wider treatment of the cancer which might also involve surgery or chemotherapy.

It may be used for any of the following reasons:

- to shrink a cancer before surgery;
- to reduce the risk of a cancer recurring after surgery;
- to complement or enhance the effects of chemotherapy.

It can be used with the intent to destroy the cancer and cure the patient or, when it is not possible to cure the cancer, palliative radiotherapy may be used with the aim of relieving symptoms such as pain in order to improve the quality at the end of the patient's life.

Radiotherapy is often the preferred choice for cancer treatment; second only to cancer surgery. Radiotherapy is involved in 40% of cases where cancer is cured.[1,2] and is the primary treatment used in 16% of patients who are cured of their cancer.[3] By comparison, chemotherapy is the primary treatment in only 2% of cases.[4]

Radiotherapy can be delivered using external beam radiotherapy or internally by either inserting a radioactive source (called brachytherapy) or by drinking a radioactive liquid.

How does radiotherapy work?

Radiation exposure can damage cell DNA leading to the cell being unable to reproduce or to the death of the cell. Healthy cells are more able to repair this kind of damage than cancerous cells and, by splitting radiotherapy treatments into treatment 'fractions', it is possible to take advantage of this repair mechanism and inflict damage on the cancer while reducing damage to healthy tissues.

Treatments or ‘fractions’ are normally delivered on a daily basis with rest days to allow for the healthy tissue to repair and for the patient to recover. The precise fractionation of the radiotherapy is a crucial part of the overall radiotherapy prescription. There are many different treatment schedules: some require patients to have more than one treatment per day; some patients may be treated on consecutive days meaning that they will also have treatment at weekends.

How is external beam radiotherapy planned?

Radiotherapy treatments are always a compromise between the probability of controlling the tumour and the probability of causing harm to normal tissues.

Individual patient treatment plans are produced in order to enable the delivery of prescribed radiation doses to the disease. Every patient will undergo an individualised planning process which involves some form of imaging (usually a CT scan or MRI scan). Various anatomical structures are outlined on the images, such as the tumour and other organs of importance. Simulated beams of radiation are added in order to assess the optimum treatment and how much radiation each beam should contribute. Certain organs which lie near to the tumour in the plan are designated ‘Organs at risk’ (OARs) and need to receive low radiation doses to avoid long-term, undesirable side effects. Once a plan has been produced, approved and verified using further imaging, the patient can receive treatment.

How is external beam radiotherapy delivered?

The linear accelerator (linac) is the primary and most widely used treatment unit for radiotherapy. Radiation beams (x-rays or electrons) are produced by accelerating electrons to very high energies and, depending on the type of radiation beam required, directing the accelerated electrons onto a metal target.

The radiation beams are shaped by collimators or applicators in the linac head that precisely define radiation fields and direct them into the area to be treated within the patient (called the target volume). The linac measures the radiation output so that precisely determined radiation doses can be delivered. Modern linacs are fitted with multi-leaf collimators (MLCs) which are able to define customisable field shapes, usually to within tenths of a millimetre.

Image Guided Radiotherapy (IGRT)

The two most important characteristics of a radiotherapy treatment are the localisation of the beam to within the target volume and the amount of dose deposited in the target volume. The beam is localised within the target volume using IGRT where images of the patient are taken when on the treatment couch and in the treatment position. This means that if the target volume has moved since the previous treatment the patient can be repositioned so that the radiation targeting is improved.

IGRT can be implemented in a number of ways. The most commonly used method is to perform ‘cone-beam CT’ scans using an x-ray tube and detector mounted onto the linac gantry. A comparison is made between the CT scan from the treatment planning process and the scan made with the patient on the treatment couch at treatment delivery. A decision can then be made if the patient position requires adjusting.

Intensity Modulated Radiotherapy (IMRT)

Conventional radiotherapy is often limited in terms of its ability to avoid certain organs and to confine the dose to within the tumour region. Intensity modulated radiotherapy is a way of improving these abilities by creating radiation fields with varying intensities. Different methods are used by the different linac manufacturers to achieve these intensity modulated fields so that individual ‘beamlets’ are created.

By using these IMRT techniques to shape the radiotherapy beams, different doses of radiotherapy can be given to different parts of the treatment area. As a result, lower doses of radiotherapy can be given to healthy tissue and side effects are reduced. For these reasons, IMRT is often used to treat tumours that are close to important organs or structures. For example, when IMRT is used to treat pelvic tumours it can reduce the risk of long term bowel problems. When it's used for head and neck tumours, it can reduce damage to the salivary glands and the risk of permanent mouth dryness.

Many, but not all treatment centres in the UK provide IMRT for people that need it. It's generally accepted that IMRT should be used for 3 in every 10 (30%) people who are having curative treatment.[5] Its main use is for treating breast, head and neck, prostate, bladder and lung cancers.

When patients are referred for radiotherapy they should find out more from their clinical oncologist about IMRT and whether it's a suitable treatment for them. Arrangements can be made to refer patients to other centres if IMRT is not available at their local centre.

While the technical performance of modern linear accelerators is such that IMRT is achievable, the challenge often lies in producing the treatment plans. Instead of manually changing dose contributions from each beam, new planning software can 'optimise' beam arrangements and dose contributions to give the best possible dose distributions ('inverse planning'). Compromises often still have to be made between dose to critical organs and to the target volume. IGRT is an essential part of IMRT as there is a very short distance between the area being treated and the areas receiving a minimal dose, so the positioning of the treatment beams is critical to ensure the radiation is delivered correctly.

Rotational IMRT

IMRT can be performed either with the linac gantry at fixed angles or by treating whilst the gantry is rotated around the patient. Elekta's VMAT® (Eleckta VMAT, Stockholm, Sweden) and Varian's RapidARC® (Varian Medical Systems) solutions both work in this way. Often, two or more rotations of the gantry are required to give the desired dose distributions. Rotational IMRT can often be delivered with lower total monitor units than conventional IMRT and tends to deliver lower doses to volumes outside the target organ.

TomoTherapy® (Accuray) is another rotational IMRT solution. Unlike conventional linacs, it is designed only to perform rotational IMRT and looks like a CT scanner. Tomotherapy does not use MLCs but has a series of shutters which can open and close very quickly. As the radiation beam is rotated around the patient, these shutters are used to shield parts of the patient so creating dose distributions which can be designed to tightly conform to the treatment regions.

Stereotactic Ablative Radiotherapy / Radiosurgery (SABR)

Stereotactic ablative radiotherapy/radiosurgery, delivers an ablative (or destructive) dose of radiation to a small target volume. The doses delivered per fraction are approximately five times larger than a normal radiotherapy treatment, but the total dose over the course of treatment is approximately the same. The aim is different from conventional radiotherapy and IMRT in that the radiation dose per fraction is sufficient to destroy, rather than to damage tumour cells. Suitable tumour targets tend to be very small and many beams are used to spread the excess dose over the patient's body.

The high doses per fraction mean that geometric precision is extremely important. IGRT therefore plays a very important role in SABR/radiosurgery in making sure that the tumour is properly targeted. In regions where the target might be moving (ie in the lungs or abdomen) techniques such as 'gating' or chest compression are often employed to give superior targeting.

Linear Accelerators can be used to effectively perform SABR/ radiosurgery, and other, more specifically designed, pieces of equipment have also been developed for this purpose.

CyberKnife® (Accuray) – a linear accelerator attached to a robotic arm. The arm moves around the patient, exposing the patient to many small beamlets (hundreds per treatment). Cyberknife makes use of a number of imaging techniques to locate the tumour throughout treatment including respiratory and bony anatomy tracking.

Gamma Knife® (Eleckta)**–** directs radiation from 201 Cobalt-60 radioactive sources into cranial tumours. The device consists of a rigid frame which holds the patient’s head firm while the radiation is delivered.

Novalis Tx™ – a complete radiosurgery package using a high precision, high dose-rate linac including 2.5mm wide MLC leaves, three methods of imaging, respiratory gating and custom made planning software.

How is internal radiotherapy (brachytherapy) delivered?

The insertion of a radioactive source into a patient is termed ‘brachytherapy’. This can be advantageous as the radiation dose is more restricted to the target volume and less healthy tissue is irradiated.

It is often performed either by the insertion of radioactive wires and seeds directly into the tumour or, more commonly, by driving a single highly radioactive pellet down a transfer tube placed inside or next to the tumour for short periods of time.

It is routinely used for gynaecological, prostate, breast and skin cancers. As an example of a modern development in brachytherapy, there is now a breast treatment technique which involves the insertion of a small balloon and catheter into the tumour excision site. The radioactive source is then driven into the centre of the balloon to treat the surrounding tissues.

Who is responsible for delivering radiotherapy?

A radiotherapy service can only work through the co-operation of many different skilled groups of staff. Doctors, physicists, dosimetrists, therapeutic radiographers and technologists are registered practitioners and required in various roles to work together to provide high quality radiotherapy treatment.

Therapeutic or therapy radiographers play a vital role in the delivery of radiotherapy services by managing the treatment process for patients. Radiographers are responsible for scanning the patient before the treatment plans are produced and delivering accurate radiotherapy at each treatment. They operate the radiotherapy equipment to deliver the radiation dose accurately and, while they see the patients on a daily basis as they attend for treatment, they also have an important role in providing information, support and advice for both the patient and their carers.

Many therapeutic radiographers undertake tumour site specific roles or specialist treatment roles (at both advanced and consultant level practice), where they are responsible for their own patient load from treatment referral, through treatment to post treatment follow up. They are part of the multi-disciplinary approach to patient management by attending and participating in Multi Disciplinary Team meetings. These post holders provide continuity of care for their patients across their cancer journey with improved levels of care for their patients as well as efficiency benefits for the service.

Radiographers are also able to train as Supplementary Prescribers and have a key role in the treatment review process in many UK centres. This has been shown to help increase efficiency to the benefit of patients while also releasing oncologists for more complex treatment planning, for example.

Clinical oncologists are doctors who take overall responsibility for the patient’s treatment. They are involved with members of the multidisciplinary team in diagnosing and determining the staging of the cancer, deciding on a course of treatment and prescribing the radiation dose. The process of prescribing is complicated and involves the definition of the target volume as well as determining the radiation dose to be delivered.

Physicists develop and oversee the scientific infrastructure of the oncology centre. They are responsible for ensuring the proper calibration of radiation producing equipment and the safe use of radiation, protecting the patients, staff and members of the public in compliance with the relevant legislation.

Dosimetrists plan radiotherapy treatments based on the requirements of the oncologist. They require a good knowledge of human anatomy and equipment capabilities to produce practical, successful treatment plans. Dosimetrists also check radiotherapy plans and help with the development of new types of treatment. Dosimetrists may be therapeutic radiographers or clinical technologists.

Clinical technologists provide on-site technical expertise for radiotherapy equipment. Technicians carry out repair work on equipment as well as undertaking routine maintenance to prevent breakdowns. They also carry out aspects of quality assurance on the equipment.

What is the incidence of cancer?

Over 275,000 people a year are diagnosed with cancer in England and more than half of these should receive radiotherapy as part of their treatment.[6] However, actual access rates are significantly lower at around 38 per cent.[7]

Is radiotherapy cost effective?

Radiotherapy is highly cost effective, consuming only five per cent of the NHS's annual cancer treatment spend.[8] European estimates are that radiotherapy costs less than £2500 per course of treatment in comparison to more than £5500 for surgery and over £13,500 for a course of chemotherapy.[9] The latest radiotherapy treatment, IMRT, incurs a marginal additional cost of £500 per patient.[10]

Equipment cost considerations

A new linac costs approximately £1.5 million. There are also associated building costs of £1 million for the treatment chamber (called a 'treatment bunker'). However, a linac installation is cost-effective because the units will provide treatment for thousands of patients before they need replacing as the expected life span of a linac is 10 years.

How available is radiotherapy in the UK?

Radiotherapy is proven to be an effective method of treating cancer and the UK workforce is trained and competent to deliver the service, but, for example, in England alone some 36,000 patients a year who may benefit from radiotherapy do not receive it.[11]

Low access rates have been largely attributable to a lack of availability of the latest radiotherapy treatments. However this is changing. The recent announcement from the government about the Radiotherapy Innovation Fund will enable centres to implement IMRT to levels that are recommended from clinical research studies so that all patients who will benefit will be able to access this. Depending on where radiotherapy centres are located, some patients have to travel significant distances daily over a period of several weeks. For some, this may not be possible or desirable so alternative treatments are chosen by the patient. It is recommended that patients should be able to access treatment within 45 minutes' travelling time of their home.[12] More centres are opening which is improving access to radiotherapy for patients.[13]

Radiotherapy is currently provided by 50 NHS Hospital Trusts across England and there are a number of private providers too.[13] There are five providers in Scotland and three in Wales and one centre in Northern Ireland.

Radiotherapy is moving from local to specialized commissioning and therefore each provider will be required to deliver services in line with the agreed national service specification. This will support the drive to ensure equitable access to treatment.

What is the current funding, investment and provision situation?

Many centres in the UK currently lag behind America and Europe in introducing more targeted radiotherapy technology. Implementation has been slow because of limited resources and the lack until recently of a nationally agreed tariff to support IMRT. This funding is essential in order to enable the required technology to be purchased to support the planning and treatment processes and speed delivery.

Detailed data about every treatment delivered from every treatment machine in England is linked to cancer type and collated in the Radiotherapy Data Set. Using this data set with the MALTHUS[13] modeling tool enables sophisticated and accurate modeling which is used to calculate anticipated radiotherapy requirements including the required increases in capacity.

This enables local providers to understand any gaps in provision in their locality, and so enable effective planning to meet future needs in both capacity and type of service. More cancer centres are being built, however capacity needs to increase considerably by approximately 67% between now and 2016 to meet the growing incidence of cancer and to provide a service closer to patients' homes[13].

The DH Report 'Radiotherapy Services in England'[13] identified 26 treatment machines of the 266 linacs installed as being past their recommended replacement age and that a further 59 will require replacement within the next three years. The replacement machines will require an investment of £85-100million, significantly less than the fund for cancer drugs.

It is the responsibility of each service provider NHS Trust in England to have in place business plans to ensure that equipment is replaced and purchased on a regular basis in line with national recommendations. There are substantial costs involved in replacing out-of-date equipment and ensuring that patients have access to the latest technologies. This is a challenge for radiotherapy providers as radiotherapy has suffered from underinvestment for many years.

The one-off Department of Health (DH) Radiotherapy Innovation Fund is helping support the implementation of Intensity Modulated Radiotherapy and Image Guided Radiotherapy across the 50 NHS cancer providers (across 58 clinical sites) in England. It is essential that workforce planning is co-ordinated across the professional groups to meet the growing and changing service need. A work force integrated planning tool (WIPT)[13] has been developed to help identify future workforce requirements. This is linked to the MALTHUS tool.

There have been problems recruiting and retaining the specialist staff required to deliver radiotherapy services. The Department of Health Radiotherapy Services in England 2012 report[13] identified that the therapeutic radiography workforce has increased by 16.4% in England between 2007 and 2011 but that a further 39% increase is still required. The current average vacancy rate for the UK is 6.1%.[15]

National initiatives focused on optimising skills mix are helping to develop innovative ways of working to support the rapidly changing technological developments within radiotherapy. More investment is required to support post registration training programmes for all professional groups.

What is the public's perception of radiotherapy?

There is a **lack of public awareness and understanding** about radiotherapy's importance in treating cancer. A survey of 2000 adults from across the UK in 2010 showed that other cancer treatments – surgery, chemotherapy or targeted drugs – are rated higher than radiotherapy as cutting edge treatments.[7]

The survey revealed that only 15 per cent of people think radiotherapy is precise and 40 per cent describe radiotherapy as 'frightening', compared to just 16 per cent who said the same for targeted cancer drugs.

Campaigns, including the National Radiotherapy Awareness Initiative, are under way to reverse the long held views that radiotherapy is outdated and that it is not as effective as drug treatment.

The campaign has 3 key messages

Radiotherapy can cure cancer
Radiotherapy is cutting edge
Radiotherapy is cost-effective

Where are we now and what is required in the future to provide our patients with world class radiotherapy services?

Progress has been and continues to be made. Much work is taking place in the UK to move towards world class radiotherapy services. New services are opening and existing services expanding. IMRT is being widely implemented together with IGRT and guidance for SABR has been developed.

It is hoped that the DH Innovation fund will enable all NHS radiotherapy centres in England to deliver the recommended levels of IMRT. Around 35 providers should be in a position to deliver the specified levels by April 2013, a further nine by the end of 2013 and the remaining six by April 2014.

Radiotherapy will remain a major treatment modality for cancer for many decades to come. However, significant investment is rapidly required to support the replacement of equipment which is past its useful life.

The efficacy and cost-effectiveness of radiotherapy is likely to increase as it is combined intelligently with new drugs and as more accurately targeted technologies for delivery are developed.

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DISCLAIMER:

This document was prepared for non-radiotherapy health care professionals and users and carers to inform them of generic aspects of the radiotherapy service.

It is intended to be an overview of common issues, not a definitive guide or list of techniques or technologies.