Radiotherapy: basic principles and technical advances

Ee Siang Choong

Robert N Turner

Michael J Flatley

Abstract

Radiotherapy has been used in the treatment of malignancy for more than 100 years. Ionizing radiation damages cancerous cells leading to cell death. Treatment may be delivered externally or internally. The radiotherapy planning process includes a number of key steps to ensure accurate and safe delivery of treatment. There are a number of strategies available to improve radiotherapy, either exploiting radiobiology aspects or through advances in technology. The field of radiotherapy is exciting and evolving rapidly, with the aim of these advances to improve the outcome of patients treated for malignancy.

Keywords advances; IMRT; radiotherapy; technology

Radiotherapy has been used in the treatment of cancers for more than 100 years. It has evolved over this time, largely driven by technology and new specialist techniques. Of all patients cured of their cancer, 40% would have received radiotherapy as part of their curative treatment. It remains the second most effective treatment for cancer (next to surgery).[1] Increasingly with the use of multi-modality treatment, radiotherapy is given concurrently with chemotherapy, endocrine therapy or biological agents in radical treatments. Radiotherapy is also used as adjuvant (post-operative) therapy to reduce the incidence of future recurrence or even neo-adjuvant (pre-operative) therapy to downstage or downsize tumours to facilitate better surgical outcomes. Apart from cure, radiotherapy is often used for palliation of symptoms, for example bone pain.

How does it work?

Ionizing radiation works by damaging the DNA of cancerous cells leading to cell death. Damage to DNA can be a result of direct or indirect ionization. This can be by high energy photons (X-rays or gamma-rays) or charged particles such as electrons or protons. In photon therapy, the dominant radiation effect is through indirect ionization of water forming free radicals which then damage DNA. The five R's of radiobiology — radiosensitivity, repair, re-population, re-oxygenation and re-assortment — underpin the conventional concepts of radiation therapy, its impact on treatment and exploitable effects.[1] Research and increased understanding of these radiobiological concepts are the focus of future radiotherapy development.

Types of radiotherapy

In most cases, radiotherapy refers to external beam radiotherapy where the radiation is delivered from a machine outside the body, most commonly linear accelerators (Linacs). Alternatively, radiation can also be delivered internally from a sealed source or radioactive implant in the form of wires or seeds. This is called brachytherapy. These radioactive implants may be temporary or permanent. Another form of internal radiation uses unsealed sources for example liquid sources, which can be ingested or injected. An example of this would be radioiodine used in treatment of thyroid cancers.

The primary aim of treatment is to deliver a therapeutic dose to a target volume containing gross tumour and also potential areas of spread, for example regional lymph nodes. At the same time, the dose to surrounding normal tissue is kept to a minimum to reduce side effects, both acute and late. The dose is prescribed in units of Gray (Gy), which is a measure of the amount of energy deposited in the tissue. The total dose is delivered over a number of treatments called fractions. A radical course of radiotherapy for epithelial tumours, for example squamous or adenocarcinomas, typically requires doses in excess of 50 Gy over 3–7 weeks given daily. For more radiosensitive tumours like lymphomas, lower doses of 20–40 Gy over 2–4 weeks may be adequate. Doses in palliative treatments are often lower and depend on the symptoms, volume of treatment and duration of control anticipated.

External beam radiotherapy (EBRT)

Therapeutic radiation in a radiotherapy department is generated using the equipment below:

Linear accelerators (Linacs)

Linacs (Figure 1) have become the most widely used source in modern radiotherapy. With its compact and efficient design, a Linac offers tremendous versatility providing both megavoltage photons (typically 4–25 MV) as well as electrons with a range of energies.

The ability of Linacs to generate high energy megavoltage photon beams enable delivery of treatment to deep seated tumours whilst sparing dose to skin (Figure 2). Hence, marked skin reactions seen with earlier forms of treatment with Cobalt machines are less common. Modern radiotherapy techniques — conformal radiotherapy, image-guided radiotherapy (IGRT), intensity-modulated radiotherapy (IMRT), Tomotherapy and stereotactic radiotherapy are all delivered by specifically-modified Linacs.

With electron therapy, penetration is limited, travelling only a short distance before a rapid fall off in dose (Figure 3). This is ideal in treating superficial targets such as skin lesions or areas overlying critical structures such as the spinal cord.

Ee Siang Choong *MB BCh SpR Clinical Oncology, Leeds Cancer Centre, St James's University Hospital, Leeds, UK. There are no competing/conflicting interests.*

Robert N Turner *MB BS Consultant Clinical Oncologist, Leeds Cancer Centre, St James's University Hospital, Leeds, UK. There are no competing/conflicting interests.*

Michael J Flatley *MB ChB SpR Clinical Oncology, Leeds Cancer Centre, St James's University Hospital, Leeds, UK. There are no competing/conflicting interests.*

Figure 1 A linear accelerator (Linac). This is the most widely used source in the delivery of radiotherapy. It has the ability to generate photons and electrons for treatment of deep and more superficial tumours.

Cobalt units

Cobalt units rely on the stable decay of its man-made source (cobalt-60) and produce average beam energies of 1.25 MV. In comparison to Linacs, a Cobalt unit design is less complex. It is also much cheaper with considerably lower capital, installation and maintenance costs.

Orthovoltage units

Orthovoltage units are much limited in their use. They are generally limited to less than 600 kV and are used primarily in treatment of superficial skin lesions. Not all centres will have access to an orthovoltage unit.

Proton units

Proton therapy exploits its heavy particle characteristics in its ability to precisely deposit dose at a specific distance from the surface with very little side scatter. This results in a highly conformal technique ideal for treatment in difficult sites with close critical organs at risk, such as base of skull or spine.

In the UK, patients who are felt to benefit from proton therapy are referred abroad with funding approval from the National Specialised Commissioning Team (NSCT) as there are currently no proton units available.[2] Plans have been announced to develop two Proton Beam Therapy Centres in the UK (London and Manchester) but these will not be available until 2017.

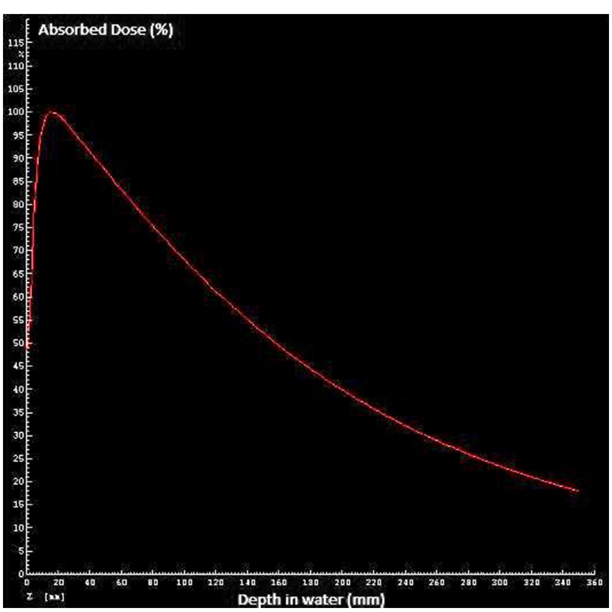

Figure 2 A depth dose curve for photons. This diagram shows the penetration of a photon radiation beam (energy 6 MV). The maximum dose of radiation is absorbed at approximately 20 mm and then falls off slowly. This allows the skin to be spared from toxicity.

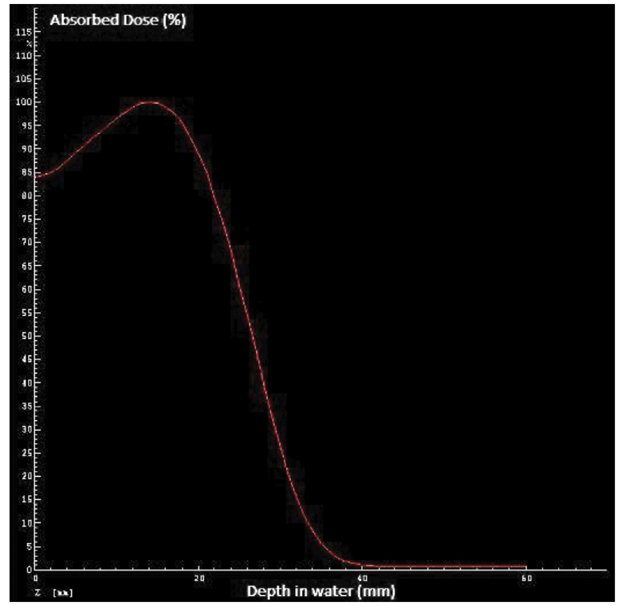

Figure 3 A depth dose curve for electrons (energy 6 MeV). In comparison to 6 MV photons shown in Figure 2, this shows that electrons travel a shorter distance. This makes electrons extremely suitable for the treatment of superficial tumours.

Planning external beam radiotherapy

The radiotherapy process includes key steps to ensure accurate and safe delivery of treatment. Following acquisition of a planning CT scan of a patient, dose to specified targets and organs at risk is simulated using a planning software program.

The following stages are described in further detail below:

- Patient positioning and immobilization
- Localization of tumour and target definition
- Treatment plan review
- Verification of plan

Patient positioning and immobilization

Radiotherapy planning is performed on a planning/simulation CT scan of the patient in the treatment position on a flat couch top (Figure 4). The patient is positioned in a comfortable, reproducible position which best facilitates delivery of radiotherapy beams. In head and neck treatments, a custom-made perspex or thermoplastic shell is often required to immobilize and allow reliable set-up of patient for daily treatment (Figure 5). Other immobilization devices include head or knee rests, vacuum bags and breast boards. 'Tattoo' marks on patient and laser pointers in the treatment room are important aids on the patient set up.

Localization of tumour and target definition

Using the CT information, the clinician then outlines the target sites with the help of any diagnostic imaging, including MRI and