CHAPTER 1

Introduction to Radiotherapy Practice

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Aim

The aim of this chapter is to provide a brief introduction and overview of the principles of current radiotherapy practice and to act as a guide for the other chapters presented in this text.

1.1 Introduction

Venturing into the field of radiotherapy physics is one of the most interesting and exciting aspects of radiotherapy practice. The rapid developments in computer and technological innovation continue to impact on changing and advancing practice.

1.2 What Is Radiotherapy?

Radiotherapy is a speciality that uses high-energy ionising radiations to treat cancer and some benign conditions. In 2015, there were 359 960 new cases and 163 444 deaths recorded from cancer in the UK. Over 50% of cancer patients survive for 10 years or more and 27% of cancer patients will receive radiotherapy [1].

The intention of radiotherapy can be curative, known as radical treatment, or it can be given to reduce the symptoms of cancer, known as palliative treatment. It can be used as a treatment modality on its own and/or combined with cytotoxic (cell toxic) chemotherapy and/or surgery.

Radiotherapy delivered from outside the body is known as external beam radiotherapy, using X-rays (photons) or electrons from a linear accelerator machine or protons produced by a cyclotron (see Chapter 8). It can also be delivered from within the body as internal radiotherapy, by placing sealed radioactive sources directly into tissue or cavities, known as brachytherapy (see Chapter 14), or by administering a fluid/capsule of radioactive material, an unsealed radionuclide, into the body (see Chapter 13).

Once a patient has been referred for radiotherapy, the aim of the treatment process is to undertake detailed imaging to visualise the tumour (see Chapter 6) followed by complex treatment planning (see Chapter 9) to ensure that accurate treatment delivery is achieved (see Chapters 7 and 10) in order to

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deliver a radiation dose that can destroy the tumour whilst minimising the dose to the surrounding healthy organs.

Radiation absorbed dose (see Chapter 4) is measured in Grays (Gy) and the therapeutic radiation dose administered varies depending upon: the curative intent of therapy; the radio sensitivity of the tumour; the volume of tissue to be treated; and the site of the tumour. To enhance the effectiveness of treatment and to allow normal tissue time to recover from the radiation injury, treatment is given in fractions over a specific period of time, for example, 45 Gy in 15 fractions over 21 days.

A combination of skill, accuracy, and complex technology are dedicated to delivering safe and effective radiotherapy in order to achieve the two competing goals – high tumour control and few treatment complications. Treatment failure to meet the treatment intent can result in the patient's clinical outcome being seriously affected in both the short and the long term. Many things can go wrong in this multi-step/person/department process and error prevention and quality management (see Chapter 11) is essential to minimise catastrophic consequences for the patient [2].

1.3 Working with Ionising Radiations

The nature of ionising radiations means that they cannot be detected by the human senses therefore, in order to be able to detect and accurately measure the amount of radiation being delivered several different methods of radiation detection and measurements have been developed (see Chapter 4).

Working with ionising radiations is safe providing a raft of measures are adopted and followed. Safe working practices are a legal requirement and follow the Ionising Radiation Legislation, the Ionising Radiation (Medical Exposure) Regulations (IR[ME]R) 2017 (IR[ME]R NI 2018) [3] (see Chapter 12).

1.4 How Radiotherapy Works

There are several interaction processes that occur when ionising radiation interacts with matter. These depend on the nature and energy of the primary radiation beam and the structure of the medium through which the radiation beam passes. For X-ray energies utilised in radiotherapy, these interaction processes are described in Chapter 5.

High-energy radiation used for radiotherapy treatment can be lethal to both normal and abnormal tissue; this is due to either direct or indirect actions occurring when the radiation is delivered to the target volume within the patient.

Direct action occurs when the cells within the normal tissue or tumour are in the mitosis phase of the cell cycle and the DNA strands are exposed as part of the cell division. The X-rays strike the DNA chain and cause either a single or double strand break; the result of a double strand break is cell death, however there is a possibility that following a single strand break cells can go on to have further cell divisions.

Indirect action occurs when the radiation ionises the water molecules within the cells and is not directly linked with the cell cycle. When the water molecule is ionised this leaves a H_2 element and an O element to restabilise and both these ions seek a partner to join with; some will become a water molecule again (H_2O) with no resultant effect. Other ions will combine as H_2O_2 (hydrogen peroxide), which is toxic to the cells' internal environment, with the resultant effect that cell death will occur.

Both of these actions are based on the probability that radiation will come into contact with either the cell during mitosis, or water molecules along their path through the patient. As the radiation cannot discriminate between normal and tumour cells there is the likelihood that normal tissue will be affected, along with the tumour, as it is impossible to clearly define the tumour boundary. As a

result of any tissue damage, cells in the vicinity will be stimulated to move into the mitosis phase of the cell cycle to repair the damage; this is true for both normal and tumour cells. With all of the tumour cells being included within the treatment volume during a course of radical treatment, the aim is to deliver a tumouricidal dose of radiation to the tumour whilst sparing as much normal tissue as possible; this is known as tumour control probability (TCP) and normal tissue complication probability (NTCP).

1.5 Radiotherapy Beam Production

Most commonly used radiotherapy beams are electronically produced using a linear accelerator; a machine consisting of a discrete number of components that function together to accelerate electrons before they strike the target to then produce high-energy photons (X-rays). These X-rays are then directed towards the patient and subsequently the tumour through a series of collimation systems. Electron beams are produced using the same principles of accelerating electrons, however the target is removed from the exit window and the electron beam is then used to treat the patient (see Chapter 8).

Proton beams are produced using either a cyclotron or a synchrotron to accelerate the particles by magnetically pulling them through a circular path until the protons reach their maximum speed. The advantage of using a proton beam is that the Bragg Peak depth can be manipulated to more closely match the tumour shape by modulating the beam as it emerges from the head of the machine (see Chapter 8).

Kilovoltage machines were historically the main provider of external beam radiotherapy, until the introduction of Cobalt-60 units, and subsequently linear accelerators; both of which have the capability to improve the delivery of dose at depth. However, kilovoltage machines (see Chapter 8) still have an important role within radiotherapy when treating superficial tumours, especially smaller lesions or lesions close to the eye.

1.6 Treatment Delivery and Planning

Radiotherapy can be delivered in different ways using a linear accelerator to deliver high energy X-rays (photons) or electrons; the majority of patients prescribed radiotherapy will receive their treatment by external photon beams. Treatment can be given with a curative intent, known as radical treatment, or to relieve symptoms, known as palliative treatment.

When delivering radical treatment the radiation dose is higher than for palliative treatment, for example, 60 Gy, and may be delivered using multiple static fields or more commonly by single or multiple radiation beams that sweep in uninterrupted arc(s) around the patient, called volumetric arc therapy (VMAT) incorporating intensity-modulated beams known as intensity-modulated radiotherapy (IMRT) designed to deliver a lethal dose across the tumour or tumour site, whilst sparing the surrounding normal tissue (see Chapter 9). Radiotherapy delivered using a linear accelerator for palliative treatments can be given by using a single field or parallel opposed fields, although IMRT/VMAT are increasingly being used for palliative treatments due to the reduced side effects of treatment. Palliative treatment usually delivers a lower dose of radiation, for example, 30 Gy.

In using IMRT/VMAT delivery the treatment planner has the ability to sculpt the doses to the shape of the target thereby optimising the radiation delivery to irregular shaped volumes. It is possible to produce concave distributions of dose in radiation treatment volumes. IMRT/VMAT has the advantage of (i) greater sparing of normal

structures like salivary glands, mandible, pharyngeal constrictors, oesophagus, optic nerves, brain stem, and spinal cord; (ii) delivery of a simultaneous integrated boost; and (iii) eliminating the need for multiple field matching. VMAT is an advanced form of IMRT which delivers IMRT-like distributions in a single rotation of the gantry, varying the gantry speed and dose rate during delivery, in contrast to standard IMRT, which uses fixed gantry position with either step and shoot or dynamic multileaf collimator shaping of the beam (see Chapters 8 and 9). Planning studies using VMAT as the mode of delivering radiotherapy demonstrate shorter planning and treatment times, fewer monitor units for treatment delivery, better dose homogeneity, and normal tissue sparing.

1.7 Treatment Accuracy and Patient Immobilisation

The first step in the radiotherapy treatment process is the accurate localisation of the tumour in reference to external landmarks. Firstly the patient must be CT (computed tomography) scanned (see Chapter 6) in the position in which they are going to be treated, for example supine with their arms elevated to remove them out of the treatment fields. The patient must be immobilised with the aim to ensure the patient is in the same position for each treatment fraction (see Chapters 7 and 10). This is required in order to deliver the planned radiation doses accurately.

Typically, a patient is CT scanned one to two weeks before they start radiotherapy and multiple tattoos may be applied to the patient's skin so that the patient's external anatomy can be aligned accurately with the treatment plan when they come back for their radiotherapy treatment. If external tattoos are to be solely relied upon for accuracy we must assume that the patient's external anatomy is constant and that the target inside the patient remains in the same position every day in relation to the external anatomy.

The patient's CT images are then loaded into a treatment planning system (TPS) which has software that is specially designed to model the energy absorption of multiple beams traversing through the body. The treatment planner selects the target volumes to be treated and the volumes or organs that are to receive as low a dose as possible (known as organs at risk) and the TPS calculates and produces a map of dose distributions, known as a treatment plan. This plan is used as a reference plan to ensure accurate and safe treatment is delivered for each treatment (see Chapter 9).

Image-guided radiotherapy (IGRT) is any imaging at the pretreatment and treatment delivery stage that leads to an action that can improve or verify the accuracy of the radiotherapy treatment (see Chapter 7). IGRT encompasses a wide range of techniques ranging from simple visual field alignment cheques, through to the more complex volumetric imaging that allows direct visualisation of the radiotherapy target volume and surrounding anatomy. The complexity of the imaging required depends on the anatomical site to be treated (see Chapters 6 and 7).

Techniques can be adopted that will assist accurate dose delivery, for example, Deep Inspiration Breath Hold (DIBH) can be used for patients with left-sided breast tumours. This can decrease the radiation dose delivered to the heart and can lower the incidence of ischaemic heart disease. This technique involves the patient inspiring to a specified threshold and then holding that level of inspiration during every radiation therapy field delivered (see Chapter 10).

1.8 Technology and Techniques

Recent technological advances allow for radiotherapy to be delivered in different modalities, such as intraoperative radiotherapy (IORT) during surgical procedures (see Chapter 8). IORT is defined as the application of therapeutic levels of radiation to a target area, such as a tumour, whilst the area is exposed during surgery. The treatment can be applied using low-energy (kV) X-rays, or with electrons. These techniques are most commonly used in the treatment of breast cancer, but can be used for other tumours, e.g. cancer of the cervix.

Proton therapy is a well-established, effective form of radiation treatment that uses a high-energy beam of protons rather than high-energy X-rays to deliver a dose of radiotherapy for patients with cancer. It works best on some very rare cancers including tumours affecting the base of skull or the spine. Proton beam treatment can be a more effective form of therapy because it directs the all-important radiation treatment to precisely where it is needed with minimal damage to surrounding tissue. The treatment is therefore particularly suitable for treating childhood cancers.

Stereotactic body radiotherapy (SBRT) or stereotactic ablative radiotherapy (SABR) is a way of giving relatively high doses of radiotherapy to a very small tumour. SBRT is delivered using a linear accelerator and delivers radiotherapy from many different positions around the body; the beams are designed to meet at the tumour. The tumour receives a high dose of radiation and the tissues surrounding it receive a relatively lower dose. This lowers the risk of side effects and increases the TCP.

1.9 Current Radiotherapy Practice

The underpinning physics principles, details of the equipment, and all aspects of practice that embrace safe and effective radiotherapy treatment are detailed throughout the chapters in this book.

References

1. Cancer Research UK. Cancer statistics for the UK [cited 4 December 2018]: Available from https://www.cancerresearchuk.org/health-professional/cancer-statistics-for-the-uk#heading-Four.
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3. European Union Directive of Euratom. The Ionising Radiations (Medical Exposure) Regulations 2017 [Internet]. Legislation.gov.uk. 2017 [cited 4 February 2018]. Available from: www.legislation.gov.uk/uksi/2017/1322/contents/made.

Further Reading

Symonds, R.P., Mills, J.A., and Duxbury, A.M. (2019). *Walter and Miller's Textbook of Radiotherapy, Radiation Physics, Therapy and Oncology*, 8e. Edinburgh: Churchill Livingstone, Elsevier.