Radiotherapy: technical aspects

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Abstract

Radiotherapy is involved in the treatment of at least 40% of cancer patients. Whereas palliative radiotherapy is typically given over 1–10 treatments, radical treatments can extend over 4–8 weeks. Radiation is delivered using external beam machines or by inserting radioactive isotopes. Localization of tumours has been transformed with spiral computed tomography, magnetic resonance imaging and positron emission tomography scanning. Modern imaging, computing and delivery systems have led to dramatic improvements in external-beam radiotherapy such as intensity-modulated radiotherapy (IMRT). Image-guided radiotherapy (IGRT) increases accuracy by imaging moving targets during treatment. Stereotactic radiotherapy allows very high doses to be delivered very precisely in a small number of treatments and is used for both intra- and extra-cranial lesions.

Keywords arc therapy; image-guided radiotherapy; intensity-modulated radiotherapy; linear accelerator; stereotactic radiotherapy

What's new?

- The use of functional imaging, such as PET, with the routine use of high-quality spiral CT and MRI enables accurate 3-D visualization of the treatment volume during radiotherapy planning
- Advanced radiotherapy techniques, such as intensity-modulated radiotherapy and arc therapies result in highly conformal treatment plans, improving target volume coverage but sparing critical structures
- Image-guided radiotherapy (IGRT) allows compensation for tumour movement during the course of radiotherapy treatment and offers the potential to reduce the conventional margins placed around tumours, thereby reducing the amount of normal tissue receiving high dose of radiation
- Stereotactic body radiotherapy (SBRT), which offers high-quality dose distributions in a small number of precise high-dose treatments is a subject of current interest that is economically attractive
- Combined chemotherapy and radiotherapy has become standard in cervical, anal and some rectal and head and neck cancers; combinations with the newer molecular targeted agents, such as cetuximab, are also in routine use

Radiotherapy has been in use for 100 years and remains second only to surgery in its curative contribution to the treatment of adult cancer. The aim is to deliver a lethal dose of ionizing radiation to tumour tissue; this damages the DNA, leading to cell death, particularly when the cell attempts mitosis. The differential effect on normal and malignant tissues is a result of several factors.[1,2]

- For a given dose of radiation, more damage may be inflicted on tumour cells than on normal cells.
- Cell and tissue kinetics usually favour recovery and repopulation of damaged normal tissue rather than tumour tissue.
- Use of fractionated radiotherapy (giving the total dose in small daily amounts) further improves the therapeutic ratio.

The impact of radiotherapy on a tumour depends on the tumour's radiosensitivity and repopulation, which describes the increase in tumour growth rate seen once treatment has started.[1,3]

Radiotherapists use external-beam radiotherapy, brachytherapy (radioactive implants) or systemic isotopes to deliver the prescribed dose to a defined volume containing the tumour and regions of potential spread, while minimizing the dose to the surrounding normal tissues and ensuring that normal tissue tolerance is not exceeded. Development of fast computer systems has facilitated treatment planning. Radiotherapy can be used for both palliative and radical patients. This article concentrates on advances in radical external-beam radiotherapy (EBRT) and should be read in conjunction with the article on *Radiotherapy: practical applications and clinical aspects* on pp 705–710 of this issue.

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Types of therapy

Radiotherapy is usually given in the form of X-rays, γ-rays or electrons; protons are a form of particle radiation, which tend to be used in very specific circumstances (see later). 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 divided into a number of fractions, typically with one fraction being delivered each day. A radical course of external-beam radiotherapy for epithelial tumours delivers a dose of 50–70 Gy over 3–7 weeks in daily fractions of 1.6–2.5 Gy. Lymphomas and seminomas are relatively radiosensitive and can be treated with lower doses of 20–40 Gy over 10–20 fractions. Palliative radiotherapy is given in lower doses, typically over 1–10 treatments.

External-beam radiotherapy (EBRT)

EBRT is usually delivered with *linear accelerators* (Linacs) (Figure 1), which can generate electrons or X-rays at energies of 4–25 MV. Linacs enable administration of high doses of X-rays to deep-seated tumours and minimize doses to the skin and subcutaneous tissue, thereby preventing the 'burns' seen with

Figure 1 A linear accelerator with cone beam for computed tomography mounted on the gantry perpendicular to the treatment head (courtesy of Varian).

earlier forms of treatment. Treatment is modified in several ways, particular by altering the direction of treatment to avoid normal tissues. Electrons penetrate only a short distance before there is a rapid fall off in dose. They are used to treat skin lesions and areas overlying sensitive structures at risk of overdose (e.g. spinal cord).

Protons are generated by a cyclotron and are therefore available in only a few centres, although internationally there has recently been a rapid increase in these. They deposit their energy at a specific distance from the surface; the resulting radiotherapy plans are highly conformal and avoid critical structures. In the UK, potentially curable tumours in close proximity to the brain and spinal cord, particularly in children, are considered as a priority for funding for referral abroad for protons.

Planning external beam radiotherapy

The planning process comprises:

- immobilization of the patient
- localization of the tumour
- design of the treatment plan
- verification of the plan.

Immobilization of the patient is used for all patients, but extra care is needed when highly sensitive structures are close to the target (e.g. the head) or very high doses are used. Devices include thermoplastic shells (Figure 2), vacuum bags for the chest or trunk and the breast board.

Localization of the tumour for radical treatment is usually performed with a CT scan in the treatment position on a flat couch top. Laser lights, tattoos and immobilization techniques are employed to increase the reproducibility of the treatment position. The images obtained give a high-quality image of the tumour and normal structures, which are outlined by the physician on each slice using PET, MRI and other relevant diagnostic information. Margins are added to account for microscopic spread, potential tumour movement and set-up inaccuracies.

Design of a radical 3-D conformal radiotherapy treatment plan is achieved with multiple fields (usually 3–4) individualized to each patient (Figure 3). Beams are shaped with the use of multileaf collimators (MLCs), which are positioned using 3-D review to shield normal structures. This has allowed safe radiation dose escalation (e.g. for prostate cancer).[4,5] CT data can be used create a reference image to confirm accurate delivery during treatment.

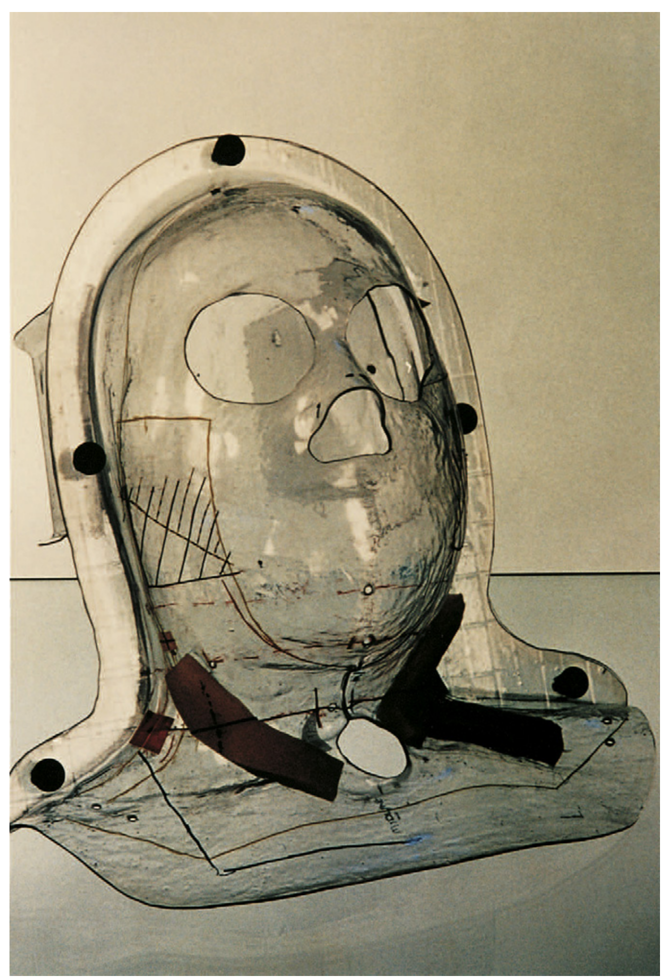

Figure 2 Thermoplastic beam-direction shell used to immobilize the head during radiotherapy and allow accurate set-up of treatment.

