Radiotherapy

Guido Heilsberg

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Radiation therapy, also known as radiooncology or radiotherapy, is a medical specialty that deals primarily with the treatment of malignant tumors with the aid of ionizing radiation.

10.1 Possibilities and Principles of Radiooncology

10.1.1 Brachytherapy

In contrast to "teletherapy", in which the radiation hits the body externally and over a distance, the distance between the radiation source and the body in brachytherapy is less than 10 cm.

Application: **Intracavitary** (the radionuclide is placed in a body cavity for a short time), **interstitial** (the radionuclide is placed temporarily or permanently in the tissue), **contact therapy** (radionuclide is placed in a carrier that remains on superficial tissue for a certain time).

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Indication for **intracavitary brachytherapy** is the vaginal application for irradiation of the vaginal stump in corpus carcinoma. However, it is also possible for small superficial carcinomas in the esophagus or other cavities. The transport of the radioactive substance to the target site is carried out remotely from a lead-resorber in the so-called **afterloading** procedure. For this purpose, the lead resor is connected via one or more tubes to the applicator, which in turn is introduced into the body cavity. For the temporary method of **interstitial therapy,** more or less flexible plastic tubes several millimeters thick are pulled through the tissue intraoperatively with a sharp metal needle. Over a period of several days, these cavities are filled several times with radioactive material, usually 192 iridium by afterloading. The technique is used for ENT tumors, large soft tissue tumors or as an interstitial boost for anal carcinoma and breast-conserving breast carcinoma.

10.1.2 Particle Therapy

In particle therapy, the **Linear Energy Transfer (LET)**, i.e. the energy transfer of a particle, plays a decisive role. The radiation quality and the relative biological effectiveness (RBE) depend on the LET of the respective radiation. A distinction is made between loosely ionizing radiation (low LET) and densely ionizing radiation (high LET); a high LET therefore has a higher biological effectiveness than a low LET.

Protons belong to the low-LET radiation group and their relative biological effectiveness is 1.1, which is approximately the same as that of photons and gamma rays, whose RBE is 1. Heavy ions with a high LET have a RBE of 2–4. The dose is expressed in **Gray equivalent (GyE)** or in RBE (relative biologic effectiveness).

Acceleration takes place via the cyclotron and the synchrotron.

10.1.3 Therapy Concepts in Radiooncology

Radiation is also used to treat benign diseases, but it is mainly used to treat cancer with the aim of curation or palliation. It can be used as the sole form of treatment or in combination with chemotherapy, antibody therapy or hormones (**"primary"** or **"definitive"**) and in combination with surgery (**pre- or post- or intra-operative radiotherapy**).

Radiotherapy Alone

Radiotherapy alone is more often used in palliative situations. Only in smaller and radiosensitive tumors is radiotherapy a curative therapy.

Radiotherapy in Series Radiotherapy can be given either in one series without any change in the irradiated volume or in several series.

The number of series and their target structures depend on the disease, the pre-treatment and also the individual situation.

Boost Irradiation The **boost** is applied to a macroscopic tumor or to an area with an increased risk of recurrence.

It is possible to perform the boost **sequentially**, i.e. following the irradiation series, or during the irradiation series either **concomitantly** or as a **simultaneously integrated boost** (**SIB**).

Radiotherapy can also be combined with other treatments (multimodal):

- Chemotherapy: e.g. for squamous cell carcinoma
- Antibodies: e.g. for ENT tumor for which chemotherapy is contraindicated
- Hormones: e.g. for prostate carcinoma
- Surgery; preoperative ("neoadjuvant") with the aim of tumor reduction; postoperative or adjuvant; intraoperative.

10.1.4 Fractionation

The standard regimens are 5 × 2 Gy/week and 5 × 1.8 Gy/week (normofractionation).

Hypofractionation

This is the reduction of fractions with a simultaneous increase in individual doses. Advantages: shorter treatment time.

Hyperfractionation

This is the increase of fractions in a unit of time. It is used if, for example, a radiation session is cancelled. The single dose to be made up is often applied before the weekend, i.e. on Friday as the second session of scheduled radiotherapy. The idea is that the normal tissue will have recovered from the sublethal (almost fatal) radiation damage by Monday.

Dose-scaled, accelerated hyperfractionation is used for tumors with a high cell division rate.

Palliation

For palliative treatment, a therapy regimen must be individually tailored to the patient's situation and the therapy goal.

10.2 Irradiation Planning

As soon as all important information about the cancer such as TNM stage, histology, receptor status, etc. is available, the patient is presented to the interdisciplinary tumor board and the therapy concept is determined. The radiation oncologist discusses the recommended procedure, the therapy and its side effects with the patient. In a physical examination, the doctor himself gets an idea of the extent of the tumor and, during the discussion, assesses whether the radiotherapy can be carried out on an outpatient basis, which positioning on the treatment table is possible or advisable and whether certain preparations are necessary, e.g. implantation of markers in the target organ or dental rehabilitation in the case of treatment in the mouth and throat area. In addition, it is clarified to what extent the patient is ready for the therapy.

The irradiation ordinance includes the following aspects:

- Intention (curative, palliative)
- Definition of the target volume
- Definition of organs at risk (OAR)
- Radiation type: photons or electrons
- Beam energy: Example six or 15 MV photons, fouror 18 MeV electrons
- Irradiation technique: standing field/multi-field irradiation, IMRT, stereotherapy, brachytherapy etc.
- Single and total dose
- Fractionation
- Positioning and positioning aids for the patient
- Name, first name, date of birth and diagnosis of the patient
- Irradiating institution, name and signature of attending specialist, date

Storage is an important preliminary measure so that the irradiation can always be applied in a reproducible manner.
- It must be as comfortable as possible.
- The planned irradiation technique must also be taken into account.
- It must be possible to reproduce it exactly.

10.2.1 Further Processing

MRI and/or PET-CT slices are superimposed on the planning CT images (= fusion, matching) and thus support the determination of the contours.

The target volume results from:
- **Tumor volume:** Tumor, possibly with lymph node metastases or distant metastases.
- **Clinical tumor volume (CTV):** macroscopic tumor + the region with scattered tumor cells.
- **Planning Target Volume (PTV):** CTV.

From many years of experience, the dose values for the individual organs are known, the exceeding of which threatens a functional impairment. In so-called **dose volume histograms,** the organ volumes that receive a certain dose are represented graphically.

> In an emergency, extensive radiation planning is not necessary.

10.3 Design and Function of Radiooncological Irradiation Equipment

10.3.1 Linear Accelerator

The classic treatment device is the linear accelerator. It consists of an X-ray machine with an accelerating tube as an additional device that provides the rays with higher energy. It is called **ultra-hard X-rays**. It makes it possible to reach deeper tumors—in contrast to conventional X-ray therapy, which has a superficial effect (► Chap. 2). The accelerator arm (gantry) rotates in one plane around the treatment table. Its position is specified as the gantry angle.

The section in which the electrons are generated is called the **electron gun.** The acceleration of the electrons is achieved by a 1–2.5 m long **accelerator tube,** which the electrons have to pass through. Here an alternating voltage with high frequency prevails. The tube ends in the beam head. There, the electron beam is deflected by means of magnets in a circular motion through 270°. As a result, the previously different energy levels of the individual electrons are brought into line with each other, and the beam becomes more homogeneous.

When the accelerated electrons collide with the **target,** high-energy photons are produced and the target is strongly heated during this process. A water pipe and a copper block are integrated in the machine for cooling. The resulting photons pass through the **primary collimator**, which is used to absorb photons that are not moving in the direction of the useful beam. In this case, the primary collimator is a lead funnel, which absorbs the rays on the walls that are not directed at the patient and therefore have no therapeutic effect. In the further course of the beam there is a balancing filter made of metal (**photon balancing body**), which homogenizes the photon radiation. A further element is the electron catcher (beamstopper or **beamhardener**). It intercepts the soft (low-energy) radiation components ("hardening").

During treatment with electrons, the radiation emerges directly (without a brake target). Instead of hitting the compensating body, the electrons hit a micrometer-thick metal foil (**scattering foil**), which expands the beam to an enlarged diameter.

The two transmission ionization chambers measure the absorbed dose in monitor units (**ME**, “MU”).

The field to be irradiated is projected onto the patient’s surface by means of a mirror in the irradiator head using a light source. The position of the light source has the same distance to the skin or surface as the brake target. It indicates the **focus-to-skin distance (FHA).**

Four tungsten or lead blocks (apertures) delimit the four field edges (**collimators**), their four apertures are movable, and the field lengths and field widths (*X*1, *X*2, *Y*1, *Y*2) are defined above them.

Before the first session and at certain intervals during the treatment, it is checked and documented whether or not radiation is actually administered exactly as specified in the calculated plan. If this verification recording takes place directly before the radiation and any necessary corrections are made immediately, this is known as **IGRT** (image-guided radiotherapy). Computer programs help to measure (**match**) the distance from given structures (e.g. bone contour, trachea, teeth) in advance. An additional metal clip (**marker**) in the tissue allows the target volume to be defined more clearly. Newer linear accelerators have a cone beam CT.

Respiratory Gated Radiotherapy

With respiratory control, only a narrow cranial and caudal safety margin is required for irradiation of lung tumors, since the respiratory tumor movement does not have to be taken into account. Similarly, the method spares the heart in left-sided breast cancer. It is only irradiated in inspiration.

Gating or Breath Hold Technique

The above-mentioned technique is called gating (gate: the gate that opens and closes). A simpler method is breath-hold radiation, which is preferably used for left-sided breast cancer to protect the heart.

10.3.2 Dose Distribution in Tissue

Deep Dose Profile

Electrons and photons both belong to particle radiation (fast-moving atoms, ions or elementary particles with rest mass), but they have different weights and behave differently as to when and to what extent they release their energy. Diagrams with so-called **depth dose curves** (Fig. 10.1) characterize the dose progression in tissue.

Decisive for the depth dose curve are: the **beam modality** (high energy photons reach deeper volumes), the **beam energy** (higher energies penetrate deeper), the **field size**, the **focus-skin distance** and the **material** irradiated.

Photons and Electrons

When it hits the skin or surface, the **photon beam** emits about 70–80% of its dose. It penetrates further into the tissue on its path and regains energy through the secondary electrons.

> The higher the energy of the photon beam, the less dose the skin receives and the deeper the dose maximum lies in the tissue.

Electrons also develop their dose maximum under the skin, but they subsequently have a different behavior than photons, because after penetrating the skin they maintain the direction of their movement and penetrate deep into the tissue (one reaches deeper PTV with them).

10.3.3 Irradiation Techniques

Isocentric and Isocentric Irradiation at the Linear Accelerator

The isocenter is the point located on the central beam at a distance of 100 cm from the target. It is where the axes of the gantry, collimator and table meet. The patient is posi-

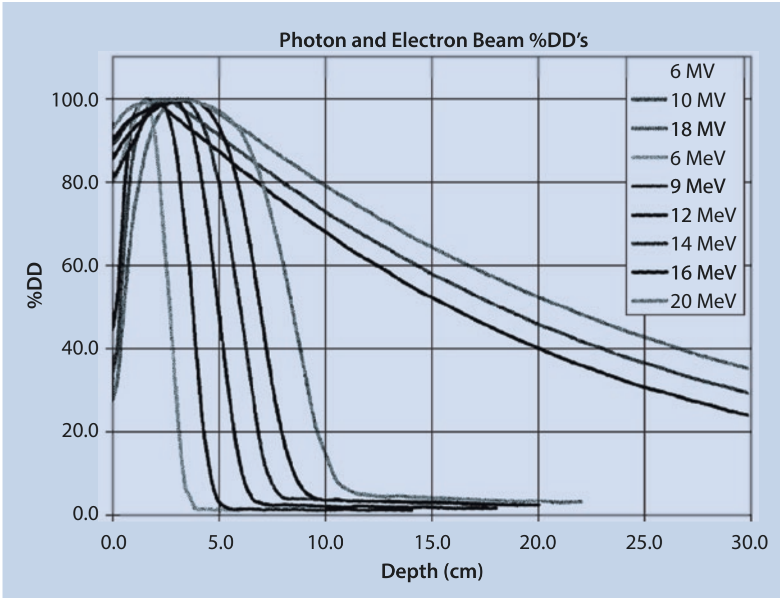

Fig. 10.1 Depth dose profile for 6–18 MeV electrons and 6–18 MV photons. *Y*-axis: Dose in percent, *x*-axis: Tissue depth. (From Purdy et al. 2012)

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tioned in the planning CT in such a way that the isocenter is in the middle of the target volume. If this is sometimes not successful, the planning computer calculates how far and in which directions the patient must be moved with the table during the initial setting (off-set) in order to meet the specification.

Coplanar Irradiation

Normally, the central beams of all fields are placed in a plane that is typically transverse to the patient's axis (coplanar irradiation). Stereotaxy, on the other hand, is a non-coplanar procedure (Fig. 10.2), which is why the table must be partially realigned during a session.

Isodoses

Isodoses are points with the same dose (connected by lines, they are called isodose curves).

Simple Techniques

Standing Field

The simplest technique is the standing field, where the field size, the hearth depth and the energy are fixed.

Counterfields

A standing field is not suitable for target volumes located deeper in the body. Counterfields (opposing single fields) halve the radiation exposure of healthy tissue.

Multi-Field Technique—Conformal Irradiation

A common technique is the multi-field method. This brings the isodoses closer to the PTV, so that the healthy tissue can be better protected.

IMRT

IMRT (intensity-modulated radiotherapy) is another method of conformal irradiation. Here, either the **sliding window technique** (irradiation while the MLC are moving) or the **step-and-shoot technique** (with irradiation interruption) are used. This allows the dose to be varied from point to point.

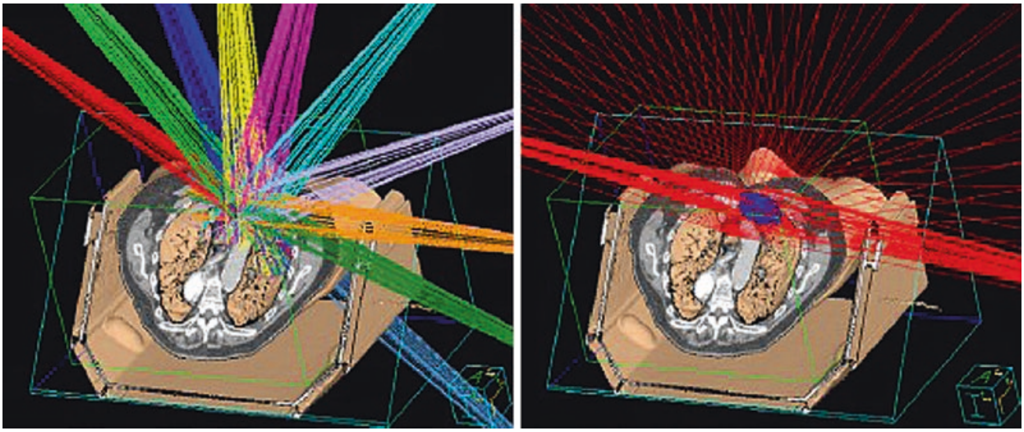

Fig. 10.2 Non-coplanar stereotaxy using ten fields compared to coplanar VMAT

VMAT

Volumetric Modulated Arc Therapy (VMAT) is borrowed from the IMRT technique: the number of small dose-modulated fields irradiated in gantry positions increases, the gantry moves in a circle or semicircle, and the irradiation time is shortened.

10.3.4 Irradiation Variants

Tomotherapy

The tomotherapy device is a combination of linear accelerator and computer tomogram. The advantages are that several volumes can be irradiated in one procedure and that long volumes can be achieved. In addition, the adjacent tissue is optimally spared in the case of shell-shaped target volumes.

Stereotactic Radiotherapy

Stereotaxy is the term used to describe radiotherapy that is applied in a spatially targeted and highly precise manner. The treatment is carried out via numerous, very small radiation fields of the linear accelerator in noncoplanar arcs. In the actual **stereotaxy** (Stereotactic Radiotherapy, SRT), treatment is administered 3–5 times, each time with high individual doses. One speaks of **radiosurgery** when the dose (12–25 Gy) is applied all at once. **High targeting accuracy** is extremely important, especially for brain radiation (e.g., for acoustic neuroma, meningioma). The **Cyberknife** is used to compensate for the movements of the patient or the target volume.

10.3.5 X-ray Therapy Equipment

For radiotherapy in the kV range, a conventional X-ray apparatus is used, but with higher voltage than in diagnostics (30–200 kV).

In many forms of heel pain (achillodynia, fasciitis plantaris, heel spur) and other inflammatory degenerative diseases, such as tennis elbow (epicondylitis humeroradialis), there is an inflammation of the soft tissues (connective tissue, ligaments, tendons) with the classic features of pain, redness and swelling in addition to the (age-related) signs of wear and tear. In these cases, X-ray therapy with small individual doses between 0.5 and 1 Gy and total doses of about 6 Gy, also called stimulation radiation, is effective.

Basaliomas and spinaliomas whose surgical removal would produce cosmetically unattractive results (e.g. on the nose, lip) or would be associated with functional limitations (e.g. on the eye) can be successfully treated with conventional therapy.

Practice Questions

1. What is IMRT and VMAT?
2. What happens during stereotaxy?
3. What are the different forms of brachytherapy?
4. What is “boost therapy”?
5. Explain the terms tumor volume, clinical target volume, and planning target volume.

Solutions ► Chap. 27