CANCER PEDIA

CLINICAL SERVICES

RADIOTHERAPY

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CHAPTER

12

RADIOTHERAPY

A. INTRODUCTION

Radiotherapy, also known as radiation therapy and radiation treatment, is used almost exclusively to treat cancer and is employed in an estimated 50 per cent of all cancer cases. [1, 2]

This chapter presents the essential elements required to establish and implement a radiotherapy service as part of a comprehensive system of cancer care. It includes a discussion of the goals and scope of the service, the resources required, management and quality considerations, and future trends. Detailed information about the establishment of a radiotherapy service can be found in the International Atomic Energy Agency's *Setting up a Radiotherapy Programme: Clinical, Medical Physics, Radiation Protection and Safety Aspect.* [3]

B. CLINICAL SERVICES

1. Goals [4-7]

Radiotherapy is a cancer treatment that applies doses of ionizing radiation high enough to damage or destroy the DNA of cancer cells, while minimizing damage to normal cells. The optimal use of radiotherapy varies by cancer type. It may be the only treatment needed to cure certain types of cancer that are localized to one area of the body. This is especially true for cancers that are very sensitive to radiation.

Radiotherapy is often used in combination with surgery and chemotherapy. Radiotherapy given before surgery – known as preoperative or neoadjuvant therapy – can be used to reduce the size of a tumour so it is easier to remove. Delivered after surgery, adjuvant radiotherapy may be used to destroy any remaining cancer cells, to ensure cancer does not recur. In some instances, radiotherapy may be used during a surgical procedure; in cases where surgically removing a tumour is likely to result in loss of function or physical disfigurement, radiotherapy may be preferred over surgery. Finally, the use of chemotherapy with radiotherapy can make cancer cells more sensitive to radiation treatment.

Radiotherapy may also be used to relieve symptoms and improve a patient's quality of life. For example, radiotherapy can shrink tumours that are pressing on a nerve, organ or bone, blocking organs such as the bowel, or affecting a person's physical functioning (e.g., ability to breathe and swallow). It is one of the main components of the therapeutic armamentarium to control cancer-related pain.

2. Scope

Radiotherapy services require upfront investment and are usually part of larger cancer centres. Comprehensive cancer centres should aim to provide the full scope of radiotherapy services, which includes two main delivery methods: external beam radiotherapy and brachytherapy (i.e., internal radiotherapy). The method selected is dependent on the type, size and location of the cancer being treated, the proximity of the cancer to normal tissues sensitive to radiation, the distance the radiation needs to travel into the body, other types of cancer treatment being received, and the patient's age, general health, medical history and other medical conditions. [8]

External beam radiotherapy delivers radiation from an external source to a tumour using a range of equipment. Medical linear accelerators – or linacs – deliver high-energy beams of photons (i.e., X-rays) as well as electrons. Cobalt radiotherapy machines, or cobalt units, deliver high-energy gamma rays emitted by the radioactive isotope cobalt-60. Both linacs and cobalt units are capable of treating tumour sites deep within the patient. Centres may also consider having an orthovoltage unit that delivers low-energy ionizing radiation. These units are used to treat cancers that are on or close to the skin surface. Specialized versions of equipment may be available in some centres, such as the CyberKnife ® and Gamma Knife®.

Modern external beam radiotherapy equipment includes digitally-controlled systems that allow for the shaping of beams to target tumours more precisely, thereby minimizing damage to healthy tissue. These advanced computerized planning systems integrate graphical visualization modules, dose distribution calculations and robust optimization algorithms, allowing for the delivery of the following specialized external beam radiotherapy techniques.

- *Intensity modulated radiotherapy* (IMRT) delivers many small radiation beams (i.e., beamlets) of varying intensity to different areas of a tumour and its surrounding tissue. A computer is provided with a three-dimensional image, planning parameters, and the distribution of radiation doses that need to be received by each area of the tumour and the surrounding tissue. The computer's software program then generates the modulated beam intensity profile, and identifies the number of required beams and treatment angles.
- *Volumetric modulated arc therapy* (VMAT) – which is a refinement of IMRT – continuously delivers modulated dose radiation beams via a constantly moving machine. The advantages of VMAT include quicker dose delivery and a significantly shorter treatment time.
- *Image-guided radiotherapy* (IGRT) relies on images of the patient taken before treatment delivery. Computers process the images and identify any changes in the patient's tumour size and location. Based on this information, adjustments are made to the patient's position before radiation is delivered.
- *Stereotactic radiotherapy* is an advanced image-guided procedure that precisely delivers a very high dose of radiation to a targeted, well-defined area. Radiosurgery procedures include: stereotactic radiosurgery (i.e., a single dose); fractionated stereotactic radiotherapy (i.e., a few doses usually used to treat brain, head and neck tumours); and stereotactic body radiotherapy (i.e., one or a few doses of radiation aimed at other body tumours).
- *Intraoperative radiation therapy* (IORT) is administered during surgery and is used when there may be concerns that surgery has not completely removed a cancerous tumour.

Brachytherapy places sealed radioactive material inside or on the surface of the body. Brachytherapy minimizes the exposure of healthy tissue to radiation, since the radioactive sources used in brachytherapy only affect tissues in close proximity. Cancer centres should have the capacity to use a range of brachytherapy techniques and modalities. There are two main types of brachytherapy, as described below.

- *Low-dose rate (LDR) brachytherapy* is delivered continuously over one to seven days, and usually involves a hospital stay. LDR uses lower-dose radioactive sources that may be loaded manually into an applicator (e.g., a needle with a plunger that has been placed in the patient) or driven into the applicator by a remote after loading unit. Alternately, the source may be put into a special device (i.e., plaque) that is sewn over tumours for a limited

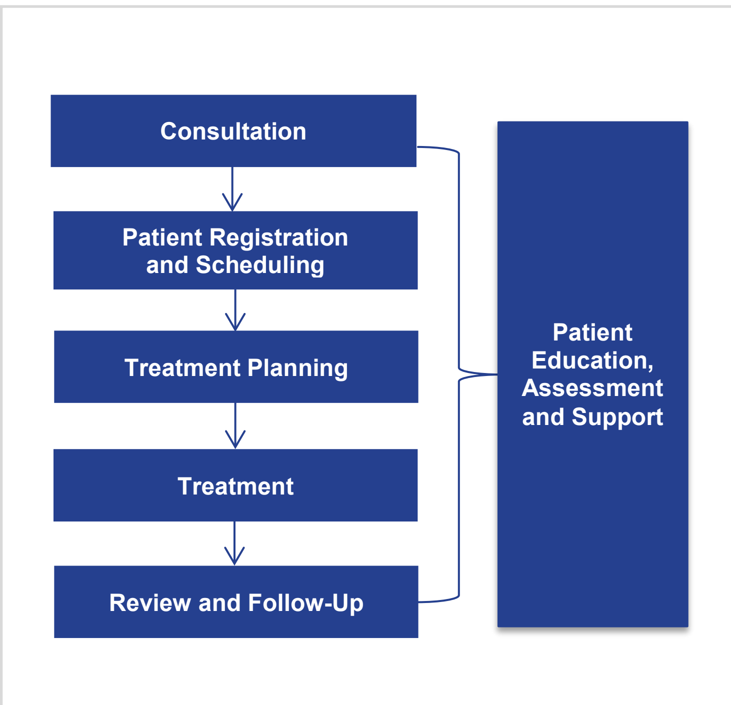
period of time to deliver the planned dose of radiation. The source remains in or on the patient during his or her stay in the hospital. Permanent implants may also be inserted through different techniques into the diseased area. These radioactive sources spontaneously decay and deliver the prescribed dose over time, which is variable and dependent on the isotope being used.
- *High-dose rate (HDR) brachytherapy* tends to be delivered in a few minutes, is generally an ambulatory procedure, and may include a few treatments over several day or weeks. An HDR procedure involves the use of a remote after loader that connects to a catheter. The device delivers a radioactive source to the tumour for a predetermined period of time. At the end of treatment session, the after loader removes the source from the catheter.

Brachytherapy can be used along with external beam radiotherapy. It can also be used to deliver radiation during surgery (i.e., IORT).

3. Pathway [9]

The radiotherapy pathway is detailed below and illustrated in Figure 1.

Figure 1: The Radiotherapy Pathway



The pathway begins with ***consultation***. A patient with cancer meets with the radiation oncologist to discuss the potential role of radiotherapy in treatment. The radiation oncologist reviews the patient's information, including his or her diagnostic imaging results, laboratory and pathology results, and other health-related tests and information, examines the patient, and determines whether radiotherapy should be prescribed as treatment. Once radiotherapy is prescribed, the patient must provide informed consent for treatment to proceed.

Patient registration and scheduling enables the documentation of all appointments, treatments, results and other important patient information in the radiation oncology information system and the patient health record. The registration and scheduling office should use standardized procedures to register patients, schedule patient appointments, manage underused or released appointment time, and address instances when scheduled appointments need to be cancelled. Important considerations for scheduling radiotherapy include the urgency of the patient and the details of his or her treatment (e.g., start date, type and length of treatment). [10] It is typical for the radiation oncologist to contact the cancer centre's radiotherapy registration and scheduling office to schedule a treatment planning appointment for the patient.

Treatment planning provides detailed information to guide radiotherapy. A detailed radiation treatment plan is a key requirement for the safe, effective delivery of radiotherapy. Whereas the treatment prescription outlines the area to be treated, the overall dose of radiotherapy and the radiation fractionation pattern, the treatment plan describes in detail:

- The target/treatment area, which includes the clinical volume (i.e., the diseased tissue) plus the additional physical volume around the tumour that is normal tissue into which undetected cancer may be spreading.
- The radiation dose to be delivered to the tumour in each treatment session, and the time period of treatments.
- The radiation dose that will be allowed for the normal tissues around the tumour.
- The safest angles or pathways for external beam radiotherapy to be delivered.
- The radiation beam arrangement and the specific dose required from each beam to deliver the desired treatment to the target area.

Radiotherapy simulation is a process used to plan external beam radiotherapy and brachytherapy. Simulation precisely identifies the area to be treated and the healthy tissue to be protected and ensures consistent patient positioning throughout treatment. Radiotherapy simulation includes three main activities: [3]

- The provision of *immobilization devices* required to position a patient accurately for treatment, maintain their position during treatment and ensure consistent positioning over the course of radiotherapy. Devices can be made for any part of the body, as appropriate to the cancer location, the immobilization required for treatment and the goals of radiotherapy, and may include fitted thermoplastic masks and shells, rigid head fixation wedges and headrests for comfortable resting positions, and stereotactic frames that use vacuum systems and compression plates to provide rigid body fixation and respiratory control. Reusable standard positioning devices are available for some circumstances. Other cases require custom-made devices.
- *Imaging simulation*, which obtains radiologic images of a patient to identify the precise areas to be targeted for treatment, design the best way to deliver radiotherapy and determine how to position the patient for radiotherapy. Imaging simulation mimics the radiotherapy treatment session without radiation being delivered.
- The application of *guiding marks* to the patient's skin to outline the treatment field and help guide the radiotherapy beams in a reproducible way during treatment. These small dots are usually permanent tattoos that can be used to guide additional radiotherapy in the future, if required.

Once a treatment plan is developed, patients are scheduled for treatment.

Treatment begins when the first radiotherapy session takes place. Patients treated with external beam radiotherapy usually have one to 30 or more daily treatment sessions.

To verify correct patient positioning, megavoltage (MV), kilovoltage (kV) or magnetic resonance images are taken and matched with simulation images. Necessary adjustments are made to ensure the precise alignment and optimal positioning of the patient for radiotherapy. The same set-up process is repeated before each treatment. If multiple treatments are needed, repeat images are taken periodically (e.g., daily, weekly) to ensure that the patient remains properly positioned over time. Radiotherapy using an orthovoltage unit does not usually require imaging for visible tumours (e.g., on the skin); rather, the patient sits on a chair or lies on a couch and the unit is positioned over the visible tumour.

Review and follow-up occur during treatment and after a course of treatment is finished, respectively. The radiation oncologist and/or oncology nurse conduct regular review visits (i.e., usually weekly during the treatment phase) to identify the patient's ongoing care needs, assess the patient's response to treatment and address any side-effects. At the end of the course of treatment, follow-up visits are arranged at intervals dependent on the specific disease and the patient's condition and characteristics.

Patient education, assessment and support occur throughout the pathway. During the consultation phase, patients receive information and educational materials about radiotherapy in general, as well as information specific to their treatment. Information is provided throughout treatment planning, generally by radiation therapists. Over the course of treatment, staff regularly assess the patient, manage symptoms and side-effects, answer questions, address concerns about treatment and provide ongoing support. For more information about patient education and support, see the *Cancerpedia: Patients* chapter.

C. RESOURCES

Given that radiotherapy is unique to cancer care, the structure of the radiotherapy service is generally the same regardless of whether a cancer centre stands alone or is part of a larger healthcare facility. All radiotherapy programs require specially-designed facilities that ensure adequate radiation protection for staff, patients, and the public [3] as well as appropriate equipment, skilled human resources and an information management infrastructure. Various factors may impact the level and configuration of the resources in a particular centre; for example, more resources may be needed to support higher patient volumes and highly-specialized radiotherapy techniques.

4. Important Considerations

Radiotherapy uses ionizing radiation and special precautions are required to ensure staff and patient safety. All decisions about radiotherapy resources must meet the radiation quality and safety standards, building codes and other requirements set by the regulatory bodies of the jurisdiction in which the cancer centre is located. Numerous standards and guidelines exist at the national and subnational levels that govern the physical infrastructure requirements for radiotherapy. For example:

- The Australian Radiation Protection and Nuclear Safety Agency [11] regulates the use of radiation through licensing, compliance, inspection and enforcement.
- The Canadian Nuclear Safety Commission [12] regulates the use of nuclear energy and materials, reviews and approves infrastructure building plans and grants licenses for construction. It also ensures that construction standards have been met before granting licenses to operate.
- The Canadian Standards Association [13] has radiation therapy standards that include requirements and guidance for infrastructure planning, design and construction.
- The United States Nuclear Regulatory Commission [14] licenses and regulates the use and storage of radioactive materials, including those for therapeutic medical use. Individual states may assume regulatory authority if they meet the requirements to become member states.

In addition, the International Commission on Radiological Protection maintains and continually develops the International System of Radiological Protection, which is a worldwide, common basis for radiological protection standards, legislation, guidelines, programs and practice. [15] Through its reports, the commission has provided advice on radiological protection and safety in medicine related to protecting the patient, preventing radiotherapy accidents and preventing accidental exposures. [16] The International Atomic Energy Agency also offers a compendium on designing and implementing a radiotherapy program that includes infrastructure requirements, including facility and equipment requirements. [3]

More detailed resources relating to radiation safety and protection can be found in the *Management* and *Quality* sections of this chapter.

Radiation protection can translate to significant infrastructure needs with respect to facilities design, physical space and materials. The penetrating ability of radiation is directly related to its energy. The higher the energy of the radiation delivered by radiotherapy equipment, the more shielding is required to protect staff, visitors and the general public from radiation exposure. It is important for cancer centres to carefully consider the implications of radiation protection in their planning, to ensure that appropriate resources are matched to service offerings.

5. Facilities and Equipment[3]

Overall, the design and layout of radiotherapy facilities should:

- Ensure radiation safety for both patients and staff
- Support the effective, efficient and safe flow of radiotherapy patients
- Consider adjacencies, including which areas and departments must be directly connected versus conveniently connected using restricted (i.e., non-public) corridors or elevators, as well as which areas and departments can be located at a distance from one another

Specific physical facilities and equipment considerations for each type of radiotherapy, as well as special considerations for patients, are described below.

External Beam Radiotherapy[3]

External beam radiotherapy occurs in a vault – also known as a bunker – that offers sufficient radiation protection and space for radiotherapy equipment and safe treatment.
Vaults should have a single entrance to enable the monitoring and management of radiation as well as the flow of staff and patients into and out of the area. The vault entrance may have a lead-lined door that is closed before treatment begins. Depending on the size of the room and the amount and type of energy emitted by the unit, the door may be replaced or supplemented by a maze that provides quicker access to the treatment area and results in shorter treatment times. Requirements for the size and complexity of this maze and the thickness and density of its concrete barriers may vary depending on the type of equipment being housed. The construction of vaults must allow for wiring and cooling/heating, ventilation and plumbing systems without breaching radiation protection. When designing and building vaults, cancer centres should also consider access for equipment installation, replacement, service and maintenance. Co-ordinating with, and obtaining specifications from, equipment vendors or other radiotherapy centres may be useful in planning.

In addition to the design and construction considerations above, subnational and/or national regulatory bodies may stipulate the following requirements for vaults:

- Types of walls, ceilings and floors
- Types of lighting and lighting controls in the treatment room (e.g., indicators for “source on” or “beam on” and “beam off”)
- Heating, ventilation and air conditioning (HVAC) systems, to maintain appropriate temperatures and air handling and balancing
- Appropriate electrical system and voltage levels, a stable power supply and backup emergency power systems for outages
- Plumbing systems, including a chilled water supply, hand hygiene sinks, a reliable water supply, drains, sprinkler systems, etc.
- Oxygen, vacuum and gas systems
- Radiation safety devices, such as doors that prevent unauthorized access and switch off the radiation beam if the door opens
- Emergency controls to shut off the radiation in emergency situations
- Appropriate signage about the use of radioactive materials and hazards
- Space and shelving to store treatment devices, immobilization devices, blocks and other equipment

The most common equipment used to deliver external beam radiotherapy is the medical linear accelerator, or linac. Basic linacs that have more specialized features need space to support additional equipment capabilities (e.g., moving motorized gantry requiring rotation space; moving treatment table; multi-leaf collimator with motorized rotation; built-in CT for image-guided radiotherapy; etc.). Linacs can also be equipped with software that allows for specialized treatments, which may carry specific facility-related requirements. For example, IORT requires shielded operating rooms or, alternatively, appropriate infrastructure and resources for the complex transferral of the patient under anaesthesia from the operating room to the vault. Dedicated mobile, miniaturized linacs may have different shielding requirements.

Requirements for cobalt units are similar to those for linacs. The radioactive isotope cobalt-60 used in these machines must be exchanged approximately every five years. Orthovoltage units are smaller, moveable and adjustable and generally require less space than other radiotherapy equipment.

A treatment control room should directly adjoin the vault and be properly shielded. When the patient is set up for treatment, staff must leave the vault to avoid radiation exposure. Telecommunications systems are required to enable visual patient monitoring and two-way auditory communications between staff and patients during treatment (e.g., intercoms, monitors, closed circuit televisions, telephones, call systems, etc.). As well, the treatment control room should house any computer equipment that links the treatment machine with treatment calculation systems, electronic imaging systems and information management systems.

Other space adjoining the vault should be appropriately shielded, depending on how the space is used (e.g., storage space, utility space, vacant space).

Brachytherapy [3]

Brachytherapy involves a minor procedure requiring a preparation room and/or an operating or special procedures room, depending on the type of procedure. Whereas LDR patients typically stay at the hospital as inpatients, HDR patients receive care on an outpatient basis. For more information about the facilities and equipment requirements of inpatient and outpatient care, see the *Cancerpedia: Inpatient Care* and *Cancerpedia: Outpatient/Ambulatory Care* chapters. Radioactive sources employed in brachytherapy – including unused sources – must be stored in secure containers in appropriate storage facilities. All source, treatment/procedure and inpatient/outpatient rooms associated with brachytherapy must be shielded according to national standards, which are specific to the sources and techniques being used.

In addition to the infrastructure considerations above, subnational and/or national regulatory bodies may stipulate the following facility requirements related to brachytherapy:

- Types of walls, ceilings and floors
- Types of lighting and lighting controls in the treatment room
- HVAC, to maintain appropriate temperatures and air handling and balancing
- Appropriate electrical systems and voltage levels, a stable power supply and backup emergency power systems for outages
- Plumbing systems, including a reliable water supply, drains, sprinkler systems, etc.
- Oxygen, vacuum and gas systems
- Radiation safety devices, such as doors that prevent unauthorized access into treatment areas and mechanisms that retract the source into a shielding device if a door opens during treatment
- Emergency procedures to remove the source from the patient and store it safely in the event of an equipment failure

- A battery-operated detector of scattered radiation at the immediate exit of the treatment room
- Appropriate signage about the use of radioactive materials and hazards
- Space and shelving to store treatment devices and other equipment
- Sinks for hand hygiene and to clean equipment

In terms of equipment, some forms of brachytherapy require the use of a remote afterloader, which delivers the radioactive source to the tumour during treatment and removes the source from the body once treatment is complete. Manual applicators may be used in LDR. Positioning for brachytherapy occurs with the aid of a range of imaging modalities, including ultrasound, computed tomography (CT) and magnetic resonance imaging (MRI). Both types of brachytherapy require a fluoroscopy unit to verify the location of sources in the body. Other equipment requirements may include catheters, needles and surgical supplies for the attachment of plaques.

A treatment control room should directly adjoin the procedure room and be properly shielded. Telecommunications systems are required to enable visual patient monitoring and two-way auditory communications between staff and patients during treatment (e.g., intercoms, monitors, closed circuit televisions, telephones, call systems, etc.). As well, the treatment control room should house any computer equipment that links the treatment machine with treatment calculation systems, electronic imaging systems and information management systems.

Other space adjoining the procedure room should be appropriately shielded depending on how the space is used (e.g., storage space, utility space, vacant space).

Treatment Planning

Immobilization devices may be made in different areas of the cancer centre, dependent on the type of device. Less complex devices that have minimal workspace, equipment and ventilation requirements may be made in the simulator room. In this instance, appropriate space to store supplies and develop the devices (e.g., sinks) should be incorporated into the layout and design of the simulator room. A dedicated mould room is usually required to make custom-designed immobilization devices that have higher resource requirements (e.g., blocks and compensators). The mould room requires appropriate space and counters to accommodate equipment and make devices (e.g., cutting, pouring and mounting blocks), equipment storage space, supporting equipment (e.g., sinks), and systems that meet regulatory requirements for electricity, HVAC and plumbing, including a sprinkler system.

Mould rooms and simulator rooms should be located in the same area, with no public access. Simulator rooms require appropriate shielding that meets regulatory radiation protection standards. An appropriately constructed and shielded viewing room is also required to protect staff while scans are being taken. Other specific requirements for the simulator room may include:
- Appropriate walls, ceilings, floors and lighting
- HVAC, to maintain appropriate temperatures and air handling

- Appropriate electrical system and voltage levels, a stable power supply and backup emergency power systems for outages
- Plumbing systems, including sinks, a reliable water supply, drains and a sprinkler system
- Oxygen, vacuum and gas systems
- Appropriate locations for patient positioning lasers mounted on walls
- Systems that enable two-way communication between the patient and staff during imaging
- Space and shelving to store immobilization devices, blocks and other equipment

In terms of equipment, a radiotherapy simulator is required. Conventional radiotherapy simulators are X-ray machines that emulate radiotherapy treatment. X-ray simulators have been largely replaced by CT simulators. CT simulators are specially designed for radiotherapy and incorporate a flat tabletop with a wide surface to accommodate patient treatment positions not common in diagnostic settings, a movable laser system that projects the radiation co-ordinates to guide marks and/or tattoos, and software that is capable of connecting simulation information with other planning and treatment systems. [17] CT simulators may be augmented by additional features; for example, four-dimensional CT enables the accurate imaging and treatment of tumours that move due to natural functions, such as breathing.

On rare occasions, dose delivery beams are manually calculated. [3] Typically, a specialized treatment planning system and software are used. Planning software provides key technical information for the radiotherapy plan and should be designed to export plan information – including beam parameters and reference images – to treatment devices or oncology management systems according to the Digital Imaging and Communications in Medicine (DICOM) standard. [18]

Other Requirements

The cancer centre must provide clinic space (i.e., examination rooms) for radiation oncologists to consult privately with patients. At a minimum, examination rooms should be equipped with standard examination tables, chairs, and instruments and supplies that enable oncologists to conduct physical examinations of patients and view medical images. For more information about clinic space, see the *Cancerpedia: Outpatient/Ambulatory Care* chapter.

Physical space must also be set aside for patients who are waiting or preparing for treatment planning or radiotherapy, including space for patients who are on stretchers. Spaces that are routinely occupied, such as waiting rooms, change rooms and washrooms, should be located away from treatment rooms. These areas must meet patients' need for privacy, confidentiality and security (i.e., for storing belongings safely).

Finally, sufficient space is required for patient registration and scheduling activities, including the filing and storage of patient health records. A registration and scheduling system is needed to manage patient activity. Ideally, this system is supported by scheduling software accessed via on-site computer terminals and linked to the radiation oncology information system. [10]

Radiation oncologists need standard evaluation forms, standard information materials about the radiotherapy process for patients, and patient-specific information. Examples of patient-specific information include details about radiotherapy for the patient's type of cancer, details about the type of radiotherapy the patient will receive, and support information, including contact details for members of the healthcare team who can answer questions. For more information about patient education and support, see the *Cancerpedia: Patients* chapter.

6. Human Resources

Radiotherapy is provided by a multidisciplinary/interprofessional team that includes radiation oncologists, radiation physicists, engineers, radiation therapists or technologists, radiotherapy nurses and a variety of allied health professionals, as outlined below.

The Radiotherapy Team

Radiation oncologists are physicians with postgraduate training in the treatment of cancer with radiation. Depending on the jurisdiction in which they practice, the radiation oncologist function may be provided by clinical oncologists with training in both radiotherapy and chemotherapy (e.g., United Kingdom, Denmark). Large cancer centres may have radiation oncologists who specialize in particular procedures and/or the treatment of particular cancers.

Medical radiation physicists – also known as radiotherapy physicists and medical physicists – have advanced postgraduate training in medical physics (e.g., a master's or doctorate degree) as well as in-hospital clinical training. Specialized accreditation of medical physics educational programs is available. In the United States, the Commission on Accreditation of Medical Physics Educational Programs evaluates and accredits graduate, residency and continuing education programs for medical physicists. [19] The European Federation of Organisations for Medical Physics oversees medical physics education in Europe. [20] Medial radiation physicists ensure that radiation equipment is working correctly and that the plan for, and delivery of, treatment supports the goals of radiotherapy.

The medical radiation physicist is responsible for:

- Selecting the centre's radiotherapy equipment, and overseeing its installation and commissioning, calibration, maintenance and continuous quality assurance checks
- Overseeing radiation protection and safety, which includes meeting all physical infrastructure safety requirements, and implementing a radiation protection and quality control program
- Working with the radiation oncologist and radiation therapist to assess radiotherapy treatment options and develop a treatment plan

Qualified ***engineers*** with specialized expertise are required to maintain radiotherapy equipment in good working order. For more information, see the *Cancerpedia: Equipment and Technology* chapter.

Radiation therapists – also known as radiotherapists, radiographers or radiation therapy technologists – have two to four years of training at a college or university. The education of radiation therapists varies by jurisdiction and scope of practice. A basic training program may be a degree or advanced diploma program. Advanced practice radiation therapy requires additional training. Increasingly, radiation therapy is becoming more specialized. For example, radiation therapists may specialize in simulation techniques (e.g., CT, MRI, positron emission tomography simulation), immobilization devices, treatment planning (e.g., target volume localization, patient contouring, shielding blocks, beam-on-time calculation), and treatment plan simulation and verification. The scope of practice of radiation therapists and the regulation of the profession vary by jurisdiction.

Depending on the jurisdiction, a radiation therapist's responsibilities may include the following.
- Performing simulation, which includes: providing/making immobilization devices; positioning the patient in the simulator bed; taking simulation images of the treatment area; and applying guiding tattoos.
- Working with radiation oncologists and medical physicists to design treatment plans, which may include computing the total amount of radiation and the dose fractions to be delivered during each treatment session. [21] [10]
- Delivering radiotherapy, including: positioning the patient for treatment; operating external beam equipment; assisting during brachytherapy procedures; operating the HDR brachytherapy unit; and recording and checking all radiotherapeutic parameters and requirements.
- Monitoring, managing and reporting to the radiation oncologist any new or unusual symptoms experienced by the patient.
- Conducting a daily assessment of the target volume coverage and adjusting patient positioning and/or the radiotherapy plan, if required, in co-operation with radiation oncologists and medical physicists.

Dosimetrists – also known as medical radiation dosimetrists – should have relevant training. Dosimetrists work under the supervision of a medical physicist to develop treatment regimens (e.g., calculate treatment dose and dose distribution, prepare LDR brachytherapy sources, etc.). They may also build patient immobilization devices and shielding blocks. Depending on the jurisdiction, the dosimetry function may be performed by individuals specifically trained as dosimetrists or radiation therapists with dosimetry training experience.

Radiotherapy nurses are qualified registered nurses with additional training in radiotherapy treatment and its impacts. Radiotherapy nurses work closely with radiation oncologists to evaluate and follow up with patients, help manage radiotherapy side-effects, and provide supportive care to the patient and family, including information and education. Other ***allied health professionals*** who work alongside nurses to provide supportive interventions to patients may include social workers, dietitians, and physical and occupational therapists. For more information about specialized nursing and allied health professional roles, see the *Cancerpedia: Healthcare Team* chapter.

Human Resource Requirements

The number of professionals required to support the radiotherapy service depends on patient volume, the range and complexity of radiotherapy techniques offered, and the type and complexity of treatments delivered at a cancer centre. The extent to which the cancer centre uses treatment planning software also impacts the number of professionals required for certain aspects of treatment planning, in particular physics. [3]

Table 1 presents an overview of radiotherapy human resource requirements as estimated by the International Atomic Energy Agency [3] and the National Cancer Institute [22] . These estimates represent aspirational goals, as even in high-resource countries workloads tend to vastly exceed the recommended staffing supports. The common, underlying human resource requirement for any cancer centre is to appoint appropriately educated professionals who have graduated from accredited programs and who have additional training in the clinical environment. Workloads may vary, but the ultimate goal of ensuring appropriate care and treatment quality and safety must always remain at the forefront of resource decisions.

Table 1: Radiotherapy Human Resource Requirements

Professional	Goal	Human Resource Requirements
Radiation Oncologist	Lead the provision of radiotherapy	*International Atomic Energy Agency estimate:* • Radiation oncologist: 1 for every 200 to 250 patients annually; higher ratios for mostly palliative patients *National Cancer Institute estimate:* • Radiation/clinical oncologist: 5 for every 1,000 patients annually
Radiation Physicist	Ensure equipment is working and help plan treatment to meet radiotherapy goals	*International Atomic Energy Agency estimate:* • Radiation physicist: 1 for up to 400 patients annually • Dosimetrist/physics assistant: 1 for every 300 patients annually *National Cancer Institute estimate:* • Medical physicist: 4 for every 1,000 patients annually
Engineer	Maintain radiotherapy and simulation equipment	*International Atomic Energy Agency estimate:* • Engineer: 1 for 2 megavoltage units or 1 for 1 megavoltage unit and a simulator serviced in house *National Cancer Institute estimate:* • Engineer: 1 linac engineer for every 1,000 patients annually
Radiation Therapist	Perform simulation, participate in treatment plan design, deliver radiotherapy and monitor patients	*International Atomic Energy Agency estimate:* • Radiation therapist for immobilization devices (i.e., mould room): 1 for every 600 patients treated annually • Radiation therapist for simulation: 2 for every 500 patients simulated annually • Radiation therapist for external beam: 2 per megavoltage unit, up to 25 patients treated daily • Radiation therapist for brachytherapy: as required *National Cancer Institute estimate:* • Radiation therapy technician: 12 for every 1,000 patients annually
Radiotherapy Nurse	Evaluate and follow up with patients, manage side-effects and provide supportive care	*International Atomic Energy Agency estimate:* • Radiotherapy nurse: 1 for up to 300 patients annually *National Cancer Institute estimate:* • Radiation therapy nurse: 4 for every 1,000 patients annually
Allied Health Professionals	Provide supportive care, nutrition advice and physical therapies	*International Atomic Energy Agency estimate:* • Social worker: as required • Dietician: as required • Physiotherapist: as required

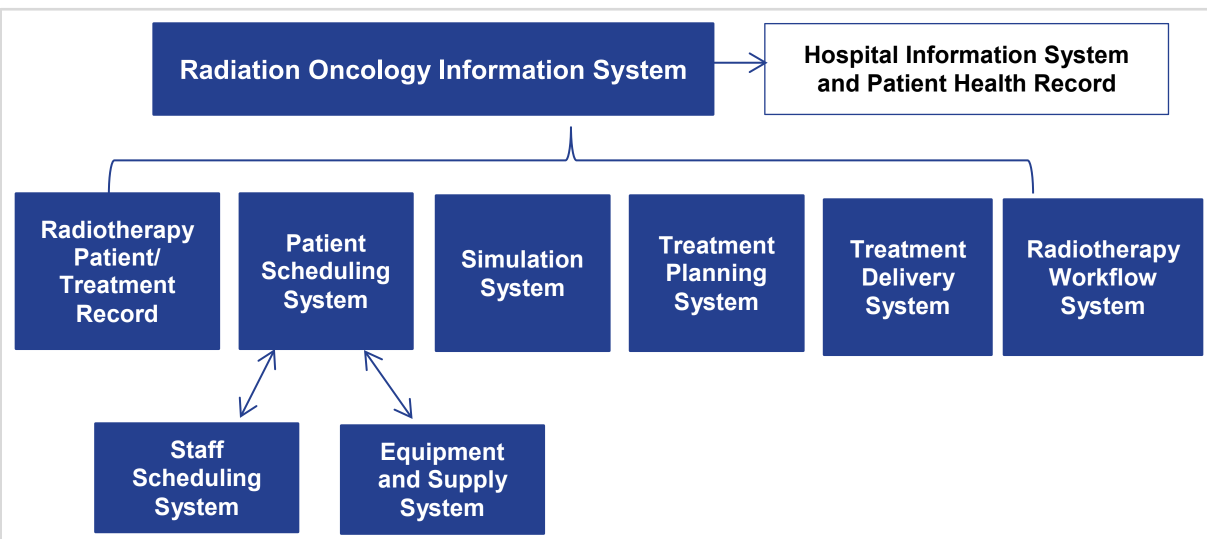
Professional	Goal	Human Resource Requirements
Radiotherapy Leadership/ Management	Oversee the radiation oncology service	*International Atomic Energy Agency estimate:* • Chief of radiation oncology: 1 for the program
	Supervise the radiation therapy service	*International Atomic Energy Agency estimate:* • Director/supervisor: 1 per centre

7. Information Management

The cancer centre needs a full information management (IM) infrastructure that provides an overarching umbrella for the radiotherapy-specific IM infrastructure. Ideally, the corporate-wide and function-specific IM infrastructure is electronic and fully integrated. In cases where electronic systems are not available, effective paper-based documentation systems are crucial.

The radiotherapy-specific IM infrastructure includes a range of interoperable information systems, all of which feed into a ***radiation oncology information system***, as illustrated in Figure 2. The radiation oncology information system is, in turn, connected to the patient health record. This is important for the ongoing care of radiotherapy patients who may need other services.

Figure 2: Information Management Infrastructure for Radiotherapy[3]



The major information systems that feed into the radiation oncology information system include the following.

The ***radiotherapy patient/treatment record*** includes patient-specific information from the following:

- Radiation oncologists, who provide requisitions for radiotherapy, radiotherapy prescriptions, and documentation of informed consent
- Schedulers, who document all scheduled patient visits and treatments

- Members of the radiotherapy team, who document information on all patient-related activities (e.g., education, assessment and supportive care) as well as the results of all patient visits and treatments

In centres that are embedded within a comprehensive network (i.e., including non-cancer specialties and disciplines), this information may correspond to the institution-wide electronic patient health record.

The ***patient scheduling system*** supports staff in scheduling patients for all visits to the cancer centre, including clinic appointments, simulation sessions, treatments, supportive care visits, and review and follow-up visits. The patient scheduling system is directly linked to the staff scheduling system and the equipment and supply system. As Figure 2 illustrates, there is a two-way information flow between these systems. Successfully scheduling patients for appointments is only possible if sufficient and appropriate staff and equipment are available. Similarly, the volume of patients impacts staff and equipment requirements.

The ***simulation system*** helps staff set parameters and requirements for immobilization devices, guides the capture of images, informs the use of contrast agents, guides the marking of tattoos and documents the optimal positioning of the body for radiotherapy.

The ***treatment planning system*** enables staff to assess simulation information and other information gathered about a patient, perform detailed calculations and develop a personalized treatment plan (e.g., number of treatments required, amount of radiation at each treatment, etc.).

The ***treatment delivery system*** allows for the export of information from the treatment planning system to radiotherapy equipment, which can then be programmed for accurate positioning and the delivery of the prescribed radiation treatment.

The ***radiotherapy workflow system*** helps staff ensure that the right services are available and organized appropriately to support the effective and efficient movement of radiotherapy patients. Workflow begins with the patient's initial radiotherapy consultation and ends with the completion of follow-up care.

For more information, see the international Digital Imaging and Communications in Medicine (DICOM®) Standard, which guides the connectivity and interoperability of many of IM systems. [18]

D. MANAGEMENT

8. Leadership

The radiotherapy program should be led by health professionals with competence in radiotherapy. Although the structure of the core leadership team may vary, generally the team should include the lead radiation oncologist or clinical head, the lead medical physicist and the lead radiation therapist. Additional representatives on the leadership team may include nurses, other health professional groups (e.g., social work), information technology and management experts, quality and risk management experts, and others. The membership and size of the core leadership team may increase depending on the size of the service and the role of the cancer centre as a referral centre.

The leadership team is accountable for planning, managing and improving radiotherapy performance, as well as the smooth functioning of an effective and efficient radiotherapy service. Each member of the leadership team should be responsible for the performance of their respective professional colleagues, for example:

- The lead radiation oncologist is responsible for medical staff and other clinical staff, including the quality of care they provide and their clinical and academic performance
- The lead medical physicist is responsible for staff physicists, physics assistants and others direct reports, including the quality of practice and care they provide and any related standards
- The lead radiation therapist is responsible for radiation therapists, including their performance and professional practice standards, and the related operations of radiotherapy planning and delivery

Advisory committees made up of key staff can complement this leadership team and bring a multidisciplinary/interprofessional perspective to the management of the service.
The radiotherapy service should hold regular multidisciplinary management meetings. In addition, there should be regular multidisciplinary meetings to discuss operational issues, including the introduction of new technologies and practices.

It is imperative that the radiotherapy management structure is clearly defined and understood by all staff. Poor management with unclear responsibilities and accountabilities can contribute to an unsafe radiotherapy service and radiation incidents. [23]

9. Operating Standards and Guidelines

Cancer centres must meet operating standards and guidelines that have been established by their national accreditation body. [24] Many countries have health service accreditation programs, whereas others adopt or adapt the programs of other countries. Accreditation standards and guidelines for hospitals and radiotherapy services set out operational requirements to support a safe and effective service.

Generally, accreditation standards and guidelines for radiotherapy address the following broad areas.

Physical Facilities and Equipment

Accreditation standards and guidelines for radiotherapy physical facilities and equipment typically include requirements to:

- Meet all planning, design and construction requirements set by regulatory bodies (i.e., subnational, national and international)

- Provide a physical layout that ensures good patient management, workflow, efficiencies and safety
- Ensure that necessary equipment and supplies are available and in good condition

Human Resources

Accreditation standards and guidelines for radiotherapy human resources require the members of the team to be fully-qualified, licensed (i.e., where applicable) and able to meet the responsibilities expected of them. Beyond this, human resource accreditation standards and guidelines may be general or specific, depending on the jurisdiction and accreditation body. A general approach tends to identify broad human resource requirements to support a cancer centre's radiotherapy services. A more specific approach may identify the competencies required of each profession working in the radiotherapy service, as well as the appropriate staff number and mix.

Radiotherapy Services

Accreditation standards and guidelines for radiotherapy services typically include requirements for the following:

- *Consultation:* Patients are evaluated and prioritized by the urgency of their condition; patients and families receive necessary information and education; patient and family rights are respected; informed consent is obtained; other physicians involved in the patient's care are informed; etc.
- *Patient registration and scheduling:* Appropriate patient information is collected; the treatment schedule takes into account the patient's clinical requirements and the effective and efficient use of resources; etc.
- *Treatment planning*: The patient's identity and treatment site are confirmed; the simulation order sets out the requirements for simulation; all simulation tests and procedures are consistent with clinical practice guidelines; simulation details are documented; the treatment plan is developed using evidence-based, best practice standards and guidelines; a radiation oncologist approves the prescribed treatment; etc.
- *Treatment:* The patient is appropriately positioned and immobilized using the results of the simulation; positioning and treatment parameters are verified; the treatment is delivered as prescribed; the treatment and any side-effects are monitored and documented; etc.
- *Review and follow-up:* Treatment is reviewed, documented and discussed with the patient and family, and understood by all, including the care team; the progress of treatment is assessed; a patient follow-up plan and process are developed and implemented.

Quality and Patient Safety

Accreditation standards and guidelines for quality and patient safety tend to focus on requirements for:

- A quality improvement plan for the radiotherapy service
- Ongoing staff education on quality and safety
- A performance improvement system that includes collecting and monitoring indicators, and efforts to improve performance

- Protocols for ongoing safety, such as the handling and use of radioactive substances and hazardous waste, safe disposal of waste, infection control, etc.

Examples of accrediting bodies and organizations that set radiotherapy standards and guidelines include, but are not limited to:
- The American College of Radiation Oncology, a professional society providing accreditation programs that include practice standards for radiation oncology. [25]
- The American College of Radiology, which offers a Radiation Oncology Practice Accreditation program. [26]
- In Australasia, the Tripartite Committee – made up of the Faculty of Radiation Oncology, The Royal Australian and New Zealand College of Radiologists, the Australian Institute of Radiography, and the Australasian College of Physical Scientists & Engineers in Medicine – which has released *Radiation Oncology Practice Standards* and a supplemental guide. [27]
- The Care Quality Commission, which is responsible for hospital accreditation and standards in the United Kingdom. [28]
- The Canadian Partnership for Quality Radiotherapy – made up of the Canadian Association of Radiation Oncology, the Canadian Organization of Medical Physics, the Canadian Association of Medical Radiation Technologists and the Canadian Partnership Against Cancer – which has released *Quality Assurance Guidelines for Canadian Radiation Treatment Programs*. [29]

For additional healthcare accreditation bodies, see the International Society for Quality in Health Care (ISQua) which accredits accrediting bodies. [30]

10. Policies, Processes and Procedures

Policies, processes and procedures reflect different and interconnected levels of activity.
- Policies are the standards and guidelines of the cancer centre that govern how it operates. The cancer centre's operating policies should reflect accreditation operating standards and guidelines. Policies drive processes and procedures.
- Processes set out what the cancer centre will do to achieve its policies. Processes usually identify who is responsible for performing the process (e.g., department), and the major functions or tasks that will be performed. Processes are high-level actions that drive specific procedures.
- Procedures identify the specific steps that will be taken to perform a task, how they will be done, by whom and when.

Cancer centres must establish policies, processes and procedures and make these readily available to all staff working in the radiotherapy service, along with training, as required. Standard operating procedures (SOPs) should be regularly assessed for their ongoing relevance and effectiveness (i.e., annually, at a minimum) and updated. Document control is critical to ensure that the most updated versions of policies, processes and procedures are being used. Although document control can be manual or electronic, an electronic system is preferable as the number of SOPs increases.

Examples of areas in which radiotherapy policies, processes and procedures should be developed include the following:

- ***Equipment and supplies:*** equipment and supply availability; maintenance procedures; etc.
- ***Infrastructure:*** electrical systems; lighting systems; fan systems; etc.
- ***Personnel:*** responsibilities of all radiotherapy personnel; staff competency testing and associated documentation; continuing education requirements; etc.
- ***Students/others:*** radiotherapy student practice; observers in the radiotherapy service; etc.
- ***Patient identification:*** positive patient identification; translation and interpretation services; patient instructions and information; informed consent; patient personal property and valuables; etc.
- ***Scheduling:*** scheduling of simulation and treatments; urgent cases; cancellation of scheduled simulation and treatments; management of underused or released simulation and treatment time; scheduling of simulation and radiotherapy equipment blocks; etc.
- ***Patient clinical requirements and follow-up:*** tests required; movement of patients to the therapy site; correct patient positioning; patient instructions (i.e., pre- and post-treatment); acute reactions; patient support; treatment review; follow-up; etc.
- ***Adverse events:*** correct patient, procedure and site; disclosure of adverse events; incident reporting; checklist process; etc.
- ***Safety:*** equipment checks; radiation levels; adverse event procedures; safety codes; for brachytherapy, body substance precautions, infection prevention and control and infection/communicable disease monitoring and management; etc.

11. Management of Patient Flow

Cancer centres should review their radiotherapy pathway, as illustrated in Figure 1. As the radiotherapy patient moves from one phase of this pathway to the next, centres must ensure that appropriate referral processes are in place, and that formal handoffs occur between the most responsible staff at each point of transition.

Table 2 outlines the management of radiotherapy patient flow at each stage of the radiotherapy pathway.

Table 2: Management of Radiotherapy Patient Flow

Phase		Management of Patient Flow
Consultation		
1.	Referral for radiation oncology consultation	• Request for consultation assessed by radiation oncologist using a standard process. • Patient is booked for consultation.
2.	Consultation with radiation oncologist	Radiation oncologist: • Provides radiotherapy consultation. • Reviews diagnostic tests, specimen pathology and other report results. • Recommends: i) radiotherapy prescription; ii) need for additional tests and investigations; and iii) need for additional specialist opinions. • Communicates with referring physician, as required, to discuss radiotherapy treatment and timing.

Phase		Management of Patient Flow
		• Co-ordinates with nursing and patient and family supports to provide information, education and psychosocial services (i.e., throughout all phases of the radiotherapy pathway).
Patient Registration and Scheduling		
3.	Registration of patient and scheduling of radiotherapy appointments	• Patient is registered in radiotherapy service. • Radiation oncologist requests patient simulation session, as required. • Registration and scheduling office contacts the patient to book a simulation appointment.
Treatment Planning		
4.	Simulation	• Patient is positively identified and prepared for simulation (e.g., instructions, clothing, etc.). • Radiation therapist positions and immobilizes patient according to planning instructions. • Radiation technologist acquires CT simulation images as well as any other simulation images recommended by the radiation oncologist. • Staff mark/tattoo patients to guide radiation delivery, as required. • Staff document the simulation in the patient's health record.
5.	Treatment planning	• Radiation therapist reviews simulation information. • Radiation therapist performs detailed calculations. • Radiation therapist develops the patient's personalized treatment plan in consultation with the radiation oncologist. • Radiation oncologist approves the prescribed treatment plan, which includes the radiotherapy to be delivered and the positioning of the patient. • Registration and scheduling office contacts the patient to book treatment appointments.
Treatment		
6.	Treatment	• The patient is positively identified and prepared for treatment (e.g., instructions, clothing, etc.). • Radiation therapist escorts the patient to the treatment room. • Radiation technologist positions the patient, consistent with the simulation and using immobilization devices, as appropriate. • Radiation technologist exits the treatment room, performs image guidance, as required, and delivers the radiotherapy treatment. • Radiation technologist assesses the patient and contacts appropriate clinical staff to address any urgent patient-related issues, if required. • Radiation technologist escorts the patient out of the treatment room to a waiting area. • Staff document the treatment/patient response in the patient's health record.
Review and Follow-Up		
7.	Review	• Radiation oncologist and/or oncology nurse examines the patient (i.e., regularly, usually weekly) to identify care needs, assess treatment and address side-effects. • Nurses and patient and family supports provides psychosocial and other support services on an ongoing basis, as required.
8.	Follow-up	• After radiotherapy is complete, radiation oncologist meets with the patient to assess progress and any radiotherapy-related issues.

12. Documentation and Data-informed Management Decisions

Cancer centres must collect and analyze radiotherapy information to ensure that patients receive services consistent with the policies and procedures of the organization, radiotherapy resources are being used effectively and efficiently, and radiotherapy practices are safe.

Documentation is required throughout the radiotherapy pathway. Table 3 presents examples of radiotherapy management indicators that may be considered for a cancer centre's minimum data set. Additional indicators depend on local circumstances. Table 3 also presents potential management analyses targeted at improving performance.

Table 3: Examples of Radiotherapy Indicators Management Analysis [31, 32]

Area	Indicators	Management Analysis
Patient	• Number of patients by demographics • Number of patients treated by intent (e.g., curative, palliative) • Number of patients by priority/urgency • Number of patients who receive information and education	• Profile of patients by age, gender, location of residence, treatment intent and priority • Analysis of patient variation over time • Rate of patient and family education compared to target, and improvement tactics
Simulation	• Number of simulations • Number of cancelled simulations and reasons why • Number of immobilization devices created by type of device	• Tracking of simulation volume changes • Analysis of simulation cancellation volumes and reasons, and improvement tactics • Tracking of volume changes in creation of immobilization devices and types
Treatment Volumes	• Number of treatments conducted • Number of treatments by anatomic site and stage of disease • Number of treatments/procedures cancelled and reasons	• Tracking of treatment volume changes • Profile of treatments by anatomic sites and disease stage • Analysis of treatment/procedure cancellations, and improvement tactics
Treatment Process Flow	• Time the patient enters and exits the treatment room • Treatment time by complexity of treatment • Unplanned interruptions over the course of treatment and reasons why • Number of treatment sessions and procedures scheduled in a time period against the number actually performed	• Number of radiotherapy delays and reasons why – i.e., patient action (e.g., late arrival), provider action (e.g., late arrival), clinical causes, non-clinical causes (e.g., equipment failure, insufficient/ inappropriate supplies, etc.), plus causal analysis and improvement tactics • Analysis of variation in scheduled and actual hours of radiotherapy, and tactics to address variations
Safety Best Practices	• Compliance with patient preparation and positioning protocols • Compliance with time-out protocols for correct patient, site and procedure • Complete, detailed and accurate documentation of consultation, simulation, treatment, review and follow-up • Compliance with quality and safety regulations and requirements	• Rate of compliance compared to target preparation and positioning protocols, and improvement tactics • Rate of complete and accurate documentation, and improvement tactics • Rate of compliance with quality and safety regulations and requirements

Area	Indicators	Management Analysis
Use of Radiotherapy Resources	• Volume of equipment and supplies used in the radiotherapy service in relation to activity • Adherence to appropriate equipment inventory, tracking, maintenance, service and decommissioning practices	• Tracking of volumes, resource utilization and costs (i.e., financial, human, capital, operating), and identification of resource gaps and opportunities for improved efficiencies that do not compromise the radiotherapy service

E. QUALITY

Quality performance in radiotherapy is critical. Radiotherapy has significant potential to treat cancer and control symptoms; however, compromised radiotherapy access and quality can result in unsuccessful and potentially life-threatening outcomes. The potential for radiotherapy quality to be compromised may increase as more advanced technologies are adopted, planning and treatment become more complex and patient volumes increase. [33] Scrutiny of activities that use radioactive substances is high at both the national and international level. As such, quality standards and guidelines exist for the use and storage of these substances.

13. Standards, Guidelines and Best Practices

Clinical Management

Clinical practice guidelines for radiotherapy are based in evidence or expert consensus, and are generally developed or recommended by larger health bodies. A number of organizations make available a wide range of cancer-related standards and guidelines, including those for radiotherapy. Radiotherapy-focused organizations that are actively involved in the development of guidelines for radiotherapy, including the following.

- American Society for Radiation Oncology [34]
- American College of Radiology [18]
- American Brachytherapy Society [35]
- Groupe Européen de Curiethérapie [36]
- European Society for Radiotherapy & Oncology [37]

For more information about evidence-based standards and guidelines, see the *Cancerpedia: Clinical Management* chapter.

Facilities and Equipment

A quality control program for infrastructure – including equipment performance and maintenance – is essential for radiotherapy quality. [3] The range of radiotherapy equipment used is becoming increasingly computerized and complex. Equipment must meet mandatory specifications and be properly commissioned for clinical use in the cancer centre. Quality control tests should be conducted to ensure that radiotherapy equipment is performing properly. In addition to initial equipment setup, ongoing regular quality monitoring of the radiotherapy infrastructure is required to ensure that equipment is consistently performing correctly. For more information about radiotherapy infrastructure quality control considerations and specifications, see the *International Atomic Energy Agency*. [3]

Human Resources

All health professional groups develop professional care standards and recommended practices for their members. Examples of bodies that set radiotherapy human resource standards and requirements include the following.

Radiation Oncology
- American Board of Radiology [37]
- American Society for Radiation Oncology [18]
- Canadian Association of Radiation Oncology [38]
- European Society for Radiotherapy & Oncology [39]
- The Royal College of Radiologists [40]
- Royal Australian and New Zealand College of Radiologists [41]

Radiation Therapy
- American Society of Radiologic Technologists [42]
- Australian Institute of Radiography [43]
- Canadian Association of Medical Radiation Technologists [44]
- European Federation of Radiographer Societies [45]
- Health and Care Professions Council (UK) [46]
- International Society of Radiographers and Radiological Technologists[47]
- New Zealand Institute of Medical Radiation Technology [48]

Medical/Radiation Physics
- American Board of Radiology [49]
- American Board of Medical Physics [50]
- Australasian College of Physical Scientists and Engineers in Medicine [51]
- Canadian College of Physicists in Medicine [52]
- Canadian Organization of Medical Physicists [53]
- European Federation of Organizations for Medical Physics [20]
- International Organization for Medical Physics [54]

Dosimetrists
- Medical Dosimetrist Certification Board [55]

Radiotherapy Nurses and Other Patient Care Professionals
- Canadian Association of Nurses in Oncology [56]
- Cancer Nursing.org[57]
- International Society of Nurses in Cancer Care [58]
- Oncology Nursing Society [59]

Radiotherapy Practices

Cancer centres must implement quality radiotherapy practices that inform patient care in the following areas.

Before Treatment

Multidisciplinary Cancer Conferences

The majority of cancer patients require a number of different clinical services from a range of healthcare providers. The multidisciplinary cancer conference (MCC) – also known as a multidisciplinary meeting – is a quality practice that guides complex, evidence-based, shared decisions about treatment. For more information, see the *Cancerpedia: Clinical Management* chapter.

Access to Care

Cancer centres should adopt a priority rating system to help guide decisions about timely access to radiotherapy based on clinical need. The system should:

- Define what is meant by a radiotherapy wait (e.g., date a patient is prescribed radiation treatment to the date when the patient receives his or her first treatment)
- Establish standard priority levels (e.g., immediate to least urgent), develop standard clinical assessment criteria for each priority and identify recommended wait time targets for each priority

The priority of a radiotherapy patient may be influenced by a number of factors, including the complexity of the patient, the type of cancer and the extent to which the cancer has spread. Cancer centres may be required to use published radiotherapy priority rating systems; for example, the province of Ontario, Canada requires all cancer centres to use a standard radiotherapy priority rating system, as illustrated in Table 4.

Table 4: Priority Categories for Radiotherapy in Ontario, Canada

Priority	Definition	Time Period
1	Patients who have an immediately life-threatening condition (e.g., neurological compromise with cord compression, superior vena cava syndrome), which is expected to be treated on an emergent basis.	1 day
2	Patients who are not considered emergent, but who, in the opinion of the treating physician, should start treatment within one week. This category would include, for example, very aggressive tumours and some palliative cases.	7 days
3	All patients who, in the opinion of the treating physician, do not meet the criteria of category 1 or 2.	14 days

Source: Cancer Care Ontario [60]

Patient-Specific Quality Assurance

Each patient's radiotherapy treatment plan is built on critical activities and decisions undertaken in the treatment planning stage. The goal of patient-specific quality assurance is to ensure that no mistakes are made, that recommended treatments are appropriate and within acceptable ranges, that appropriate targets and surrounding healthy structures have been properly delineated, and that dose calculations are correct.

Radiotherapy is becoming more automated, which has been shown to decrease error rates despite increased plan complexity. [61] However, an overreliance on automated procedures that assume systems are working correctly can contribute to radiotherapy errors. [23] Independent checking of treatment sheets is an important quality assurance activity that helps identify errors, and has also been found to improve departmental communications, educate staff and target in vivo dosimetry. [62]

During Treatment

Safety Protocols

Cancer centres must establish radiotherapy safety protocols to ensure quality and safety. Numerous international and national bodies have developed extensive guidelines and recommendations that centres can use to develop safety protocols in such areas as the use of radiation in medicine, radiation protection of patients and staff, and the handling of radioactive substances, including the following.

- International Atomic Energy Agency [63]
- International Commission on Radiological Protection [64]
- World Health Organization [65]
- Australian Radiation Protection and Nuclear Safety Agency[66]
- The Royal College of Radiologists, Society and College of Radiographers, Institute of Physics and Engineering in Medicine, National Patient Safety Agency, and the British Institute of Radiology [23]

Patient Safety Time Out

The patient safety time out occurs just before the radiotherapy procedure begins, when the patient is present and awake. The senior clinician leads this structured, final check prior to treatment. It involves all members of the healthcare team and confirms the correct patient, procedure and treatment site. Generally, all members of the healthcare team verbally confirm that:

- The correct patient is present
- The correct procedure is to be performed
- The correct treatment site/side is identified and marked, if required

For example, the Australian Commission for Safety and Quality in Health Care has developed a protocol for ensuring the correct patient, correct procedure and correct site in radiotherapy. [67]

After Treatment

Quality of Care Conferences

To advance quality radiotherapy performance, cancer centres should hold regular quality of care conferences (QCCs) after treatment is finished. For more information about QCCs – also known as morbidity and mortality rounds or morbidity and mortality conferences – see the *Cancerpedia: Clinical Management* chapter.

Throughout the Radiotherapy Pathway

Patient Education and Information

Providing patient information and education throughout the radiotherapy pathway is a key quality practice. Patients require comprehensive information that is both generic and specific. Generic information includes, but is not limited to, an overview of the cancer centre and the radiotherapy process, the radiotherapy experience (i.e., how to prepare and what to expect), possible side-effects, and general post-radiotherapy planning and care. Patient-specific information includes, but is not limited to, details on the patient's disease, the expected outcomes of radiotherapy, how to address side-effects, details of after care and contact information.

In addition to providing information and education, there must be dialogue with, and support for, the patient and his or her caregivers to address ongoing needs and concerns. For more information about patient support and education, see the *Cancerpedia: Patients* chapter.

Flow

The radiotherapy pathway is complex, as illustrated in Figure 1. A great deal of effort is required to plan, prepare and co-ordinate radiotherapy services so that patients receive safe, high-quality and timely treatment, and so that resources (i.e., human resources, financial resources, equipment and facility infrastructure) are optimized. Poor radiotherapy flow results in the poor use of resources, delayed or cancelled treatments, increased wait times, and high levels of patient and staff stress. Examples of quality performance within each phase of the radiotherapy pathway are illustrated in Figure 3.

The use of process improvement methodology is a major tactic for improving radiotherapy quality and efficiency. One common approach is lean methodology, which was pioneered by Toyota and has since been adopted by the manufacturing, service and healthcare industries. Using this approach, front line staff use a structured process to define value, map work steps, and identify and remove unnecessary steps in their work. [68] A second common approach is Six Sigma, which was pioneered by Motorola and has also been adopted by other industries, including healthcare. Six Sigma uses quantified value targets and identifies and removes the cause of defects or errors to eliminate these defects and errors and minimize variability. [69] Aspects of both approaches can be used for quality improvements. [70] For more information, see the *Cancerpedia: Quality Improvement* chapter.

Figure 3: Examples of Quality Performance in Radiotherapy

Before Treatment
- Patient receives information about their radiotherapy and care.
- Patient provides informed consent.
- Simulation tests are completed.
- Treatment is planned and verified.

During Treatment
- Radiotherapy team is appropriate for the treatment.
- Treatment room is equipped appropriately for the procedure.
- All equipment is functioning.
- Flexibility is built in to radiotherapy scheduling for emergency cases.
- Communications and teamwork are excellent.
- Patient safety time out is conducted.

After Treatment
- Patient is assessed after each treatment and any issues are addressed.
- Weekly review is conducted over the course of treatment.
- Follow-up after treatment is completed.
- Patient receives information about what to expect after radiotherapy and about side-effect management.

Outlining the radiotherapy pathway is helpful for understanding individual roles and scopes of practice, and for highlighting bottlenecks and issues that need to be addressed. Studies have shown that process improvements can have significant positive impacts, including reduced wait times. [71]

Many programs are available to help hospitals improve the quality and efficiency of radiotherapy care. Examples include the following.
- The International Atomic Energy Agency has developed a comprehensive audit tool for the quality improvement of radiotherapy practices. [72]
- The American College of Radiation Oncology has developed quality practice standards and offers an auditing process [25].

14. Performance Monitoring, Reporting and Quality Improvement

The radiotherapy service must establish a system for quality and performance management and continuous quality improvement. Quality improvement includes the following.

Quality Framework

The radiotherapy quality framework should include broad domains for performance improvement, such as patient and staff safety, staff satisfaction, and care that is timely, efficient, patient-centred, effective, accessible, equitable and appropriate. [73] These broad domains should align with the cancer centre's priorities and reflect the particular priorities of the radiotherapy service. The selection of domains may also be influenced by the external priorities of national or subnational health ministries or organizations that focus on quality in cancer care and/or radiotherapy. Examples include:

- Agency for Healthcare Research and Quality [74]
- American Society for Radiation Oncology[75]
- Canadian Partnership for Quality Radiotherapy [29]
- Cancer Quality Council of Ontario [76]
- European Partnership for Action Against Cancer [77]
- The Joint Commission [78]

A wide range of clinicians and managers should have input into selecting the domains.

Quality Performance Indicators

The cancer centre's radiotherapy service should select quality performance indicators within each broad domain. As with the selection of domains, the selection of indicators should align with the cancer centre's objectives, reflect the priorities of the radiotherapy service and may be influenced by the priorities of external bodies. A wide range of clinicians and managers should have input into selecting the indicators, and should have confidence in both the process used to select the indicators and the indicators themselves.

Quality performance measures that are most useful to clinicians include appropriate groupings of meaningful indicators, high-quality data obtained using a valid methodology and results that are published in a timely manner. [79] Indicator definitions may be adopted or adapted from other reliable sources. Indicators must be clearly defined, measurable and reliable, incorporate the use of evidence or benchmarks, and be used to manage and improve the quality of radiotherapy.

Generally, quality performance indicators should consider structures, processes and outcomes. [80] For radiotherapy:

- Structures are the settings where care takes place and the related supports (e.g., consultation clinic, patient registration and scheduling office, simulation facilities, treatment planning offices, procedure rooms, patient education and support clinics, equipment, human resources, administrative structures, program operations and policies, etc.)
- Processes refer to how the full range of radiotherapeutic care is provided (e.g., appropriate, complete, technically competent, guideline-based, safe, co-ordinated, acceptable, etc.)
- Outcomes refer to the patient's recovery, restoration of function and survival.

Other radiotherapy performance indicators should be considered that go beyond structures, processes and outcomes, such as accessibility, timeliness, cancer-related healthcare costs, quality-of-life metrics and the patient centeredness of cancer care. [81] Although numerous radiotherapy performance indicators may be available, a manageable number of indicators should be selected to track performance. Table 5 presents examples of quality performance domains and indicators for radiotherapy.

Table 5: Examples of Quality Performance Indicators for Radiotherapy

Domains	Examples of Quality Performance Indicators
Accessible	• Wait time for radiotherapy within priority rating target • Unplanned closures of radiotherapy treatment units and reasons why • Availability of radiotherapy to the population
Appropriate	• Appropriate number and mix of staff to provide treatments • Appropriate equipment and technologies for treatments • Appropriate simulation procedures • Treatment plan peer-reviewed • Treatment plan verified • Number of vaults/procedure rooms
Effective	• Use of evidence-based radiotherapy • High-level team performance • Equipment functioning appropriately
Efficient	• Flow between pre-treatment, treatment and post-treatment phases • First case and subsequent case on-time start accuracy, and reasons for delays • Time between scheduled appointment and start of treatment • Turnover time of treatment room • Per cent treatment unit utilization • Average cost per case • Average cost per radiotherapy unit hour
Patient-centred	• Patient satisfaction levels • Patient education and information
Safety	• Per cent changes in treatment plan after independent verification • Compliance with patient safety time out • Adverse events in the radiotherapy process • Near misses in the radiotherapy process (e.g., unplanned event without injury, illness or damage, but with potential for any or all of these adverse outcomes) • Equipment malfunction • Staff injuries due to safety breaches
Staff Work Life	• Staff satisfaction • Staff absenteeism • Staff efficiency • Staff turnover • Overtime hours

Quality Infrastructure

A quality infrastructure with the following elements is needed to measure, monitor and improve radiotherapy performance.

First, information management support is needed to collect, analyze and report on indicators. The timing of indicator collection may vary from just-in-time to weekly, monthly, quarterly, semi-annually or annually. Regular access to radiotherapy data and the ability to develop customized reports is critical to driving improvements. Customized performance reports may focus on certain radiotherapy treatments (e.g., external beam, brachytherapy), groups of staff (e.g., radiation oncologists, physicists, radiation therapists) or individual staff. It is best to provide performance feedback quickly and frequently, so that care and process improvements can be made. [81]

Second, a radiotherapy performance accountability team – made up of key radiotherapy leaders (e.g., radiation oncology, physics, radiation therapy, nursing and others) – should review the indicators in relation to evidence- and consensus-based benchmarks, and best practice standards and guidelines. The team should engage staff to identify areas for improvement, establish improvement targets with associated timelines, develop action plans, support the implementation of change and track improvements.

Third, radiotherapy staff should receive ongoing training in quality improvement and patient safety, including best practices, adverse events (i.e., recognize, respond, report, disclose), and human factors. The latter includes factors that can influence people and their behaviour. In the cancer centre, these are environmental, organizational and job factors, and individual characteristics that influence behaviour at work. [82]

Finally, to promote transparency and continuous quality improvement, performance information should be communicated to those working in the radiotherapy service and, more broadly, to everyone in the cancer centre. Communication should include commentary on the data, expected plans of action and successes improving performance. In addition, there may be national or subnational requirements to report radiotherapy performance in certain areas. For example, all radiotherapy departments in the United Kingdom are required to report radiotherapy errors using the same grading and classification system to the National Patient Safety Agency. [23] In the United States, the American Society for Radiation Oncology launched a safety initiative, Target Safely, to improve patient safety and reduce medical errors during treatment. [83] The initiative includes a national medical error reporting system and a patient safety database for radiation oncology.

F. THE FUTURE

Radiotherapy techniques to treat cancer continue to advance significantly. Advancements in radiotherapy have an impact on facility infrastructure and design, as well as implications for equipment, human resource and training requirements. This section presents major innovative trends in radiotherapy and describes their impact on radiotherapy cancer services.

15. Innovative Trends

Personalized Radiotherapy

Traditionally, anatomical and physiological information has been used to develop the patient's radiotherapy plan. Increasingly, knowledge of disease at the molecular and cellular levels is being used to develop more personalized radiotherapy plans for individual patients. For example, tumour marker testing is being used to help tailor radiotherapy treatments and doses to the specific tumour biology of each patient. [84]

Adaptive Image-Guided Radiotherapy

Significant improvements in imaging are fueling the advancement of image-guided radiotherapy techniques. Every organ in the human body has internal movement that can cause the radiotherapy target to move and change its shape during irradiation. [85] The use of imaging during radiotherapy provides information on the changing size and location of the tumour and the surrounding organs at risk, makes it possible to delineate a tumour precisely and avoid surrounding healthy tissue, aims radiotherapy at the tumour as it moves in real time and helps differentiate the most aggressive areas of the tumour to be treated. [86]

Adaptive radiotherapy makes it possible to assess anatomical changes within the patient and/or the tumour's response to treatment, and to modify the patient's initial treatment plan to ensure that treatment continuously aligns with any anatomical changes that occur during the treatment period. [87] [85]. This is critical, given that patients usually receive radiotherapy over a period of time. The result is more precise and accurate treatment, minimal damage to healthy tissue and decreased treatment-related morbidity. [84] More precise treatment can also reduce the number of radiotherapy sessions required. For example, with more precise treatment, it is possible to radiate a moving pulmonary tumour three times as opposed to 35 times using a much higher dose of radiation, resulting in an increased chance of curing the condition with hardly any adverse effects. [86] Research has also shown that the use of repeated MRI imaging to inform the brachytherapy implant dose has been linked to improved clinical outcomes regarding local control, overall survival and morbidity. [88]

The development of image-guided radiotherapy techniques will continue into the future.

Advances in Radiotherapy Techniques

Specialized radiotherapy techniques are continuously developing. Examples of specialized radiotherapy techniques currently in use include the three- and four-dimensional imaging of tumours to target treatment more precisely as well as hadron therapy, which uses beams made of light-charged particles such as protons or carbon.

In terms of brachytherapy, advanced techniques include computer-planned treatment that calculates the radiation dose delivery to achieve the desired dose distribution [87], and the incorporation of progressively advanced imaging modalities (e.g., ultrasound, 3D ultrasound, CT and MRI) into the insertion, planning and delivery phases of treatment. The future will see further development of these techniques.

16. The Impact of Innovative Trends

Innovative trends have an impact on the design, planning and development of radiotherapy services.

Infrastructure should ideally be designed to accommodate radiotherapy innovations, such as those described in this chapter. For example, specially-built rooms may be needed to accommodate and operate CT and MRI scanners while radiotherapy is being delivered. When surgery and radiotherapy are being conducted at the same time, operating rooms require the capacity to provide radiation therapy safely, and space for additional professionals to work in a fully-functional operating room.

Advances in specialized radiotherapy techniques and computer-planned treatment require upfront capital investments, ongoing operating and maintenance funds, and training funds. In addition, costs may temporarily increase when new techniques and treatments are being implemented. For example, stereotactic and/or adaptive radiotherapy can be costly, given the additional planning time and resources required; however, these costs may be offset by savings realized through fewer radiotherapy sessions that are more precise and targeted. Training in new radiotherapy techniques is critically important, especially for staff already in practice that need continuing education to become proficient in new modalities.

All professionals who are involved in delivering radiotherapy should engage in continuous skills development to gain the expertise needed to plan and deliver more complex therapies. With the increase in radiotherapy solutions to treat cancer, radiotherapy expertise may not remain restricted to radiotherapy alone. [86] It has been suggested that a new hybrid medical discipline may be emerging that combines the expertise of a variety of specialists, such as interventional radiologists, surgeons and others.

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