Chapter 9

Current Developments in Radiotherapy Quality Control Methods

Ayse Gulbin Kavak[1]

Abstract

Quality control is of critical importance to ensure the accurate and reliable implementation of treatment in radiotherapy. Radiotherapy is a primary method of treating diseases such as cancer, aiming to destroy cancer cells or control their growth using high-energy X-rays or gamma rays. The quality control process encompasses a comprehensive series of procedures involving regular examination and evaluation of elements like radiotherapy devices, dosimetric components, and treatment planning systems. The primary objectives of quality control are to enhance patient safety, ensure accurate dose delivery, and optimize treatment outcomes. Due to its inclusion of critical parameters and safety measures, this process holds significant importance in the field of radiotherapy.

The quality control process begins with the examination of treatment devices and components. Linear accelerators are the most commonly used devices in radiotherapy. Quality control procedures for linear accelerators involve various steps, including reference dose measurement, dose output calibration, isocenter dose measurements, accuracy of irradiation, beam profile control, and dynamic field control. The control of simulation and imaging devices such as CT simulation, MRI, PET/CT, and ultrasound plays a crucial role in radiotherapy preparation. The quality control of these devices ensures the accuracy of elements such as calibration, visualization of anatomical structures, and assessment of image quality.

Ion chambers, diode detectors, two-dimensional dosimeters, diamond detectors, thermoluminescent dosimeters (TLD), Metal-Oxide-Semiconductor Field-Effect Transistor (MOSFET) detectors, and gel dosimeters are used for the control of devices and components in radiotherapy and are examined for calibration, accuracy, and sensitivity. Dosimetric devices

1 Assistant Professor, Gaziantep University, Medical Faculty, Radiation Oncology Department, kavakgulbin@gmail.com, https://orcid.org/0000-0003-1995-1642

https://doi.org/10.58830/ozgur.pub387.c1604

like ion chambers and diode detectors are vital for accurately measuring radiation doses. Two-dimensional dosimeters and film dosimeters, with their advantages and disadvantages, contribute to treatment plan verification and patient safety. While diamond detectors offer high precision, they come with higher production costs. Thermoluminescent dosimeters, using materials like LiF, provide accurate measurements and a wide dose range. MOSFET detectors, as semiconductor-based devices, respond quickly to radiation and are valuable for real-time dosimetry during treatment. Gel dosimetry, utilizing gel materials, offers high precision in measuring radiation doses but requires complex laboratory analysis.

In conclusion, the comprehensive quality control methods in radiotherapy are of vital importance for ensuring patient safety, treatment success, and the accurate operation of equipment. These controls, conducted in accordance with national and international protocols, adapt to evolving standards and technologies, contributing to the overall effectiveness and safety of the radiotherapy process.

Introduction

Radiation therapy (RT) is a treatment method used to treat diseases such as cancer or alleviate pain. RT aims to destroy cancer cells or control their growth using high-energy X-rays or gamma rays. It can be administered alone or in conjunction with other cancer treatment methods such as surgery or chemotherapy. High-energy radiation can disrupt the DNA structure of cancer cells, halting or reducing their growth. Radiotherapy can be applied as neoadjuvant or adjuvant treatment. Neoadjuvant treatment is used to shrink or control tumors before surgery, enhancing the effectiveness of surgery. Adjuvant treatment is administered after surgery to reduce the risk of cancer cells returning. RT is also employed to control the spread of cancer cells or alleviate symptoms caused by metastatic tumors (Sonke, Aznar, and Rasch 2019)

Quality control in radiotherapy is a comprehensive process and one of its most crucial parameters. This process involves regular inspection and evaluation of elements such as radiotherapy devices, dosimetric components, and treatment planning systems. The purpose of quality controls is to ensure the safe, effective, and accurate implementation of the treatment process. Quality control is employed to enhance patient safety, ensure the delivery of accurate doses, and optimize treatment outcomes. The quality control process holds significant importance in radiotherapy (Moran et al. 2011)

Quality control in radiotherapy can be categorized into the following main topics:

Quality Control of Treatment Devices

Linear accelerators (LINAC) are among the primary devices used in radiotherapy. LINACs are devices used to accelerate high-energy particles such as electrons or protons for various applications, including cancer treatment in RT. Medical LINACs consist of essential components such as an electron gun, radiofrequency (RF) system, electromagnet fields, flattening filter, collimator, jaws, multileaf collimator, monitoring and control system, dose measurement systems, and cooling systems. LINACs must be regularly checked for dose output, energy levels, beam profiles, and other features (Létourneau et al. 2018).

Quality control for LINACs, the most commonly used devices in radiotherapy, involves fundamental steps such as reference dose measurement, dose output calibration, isocenter dose measurements, accuracy of the irradiation field, beam profile control, and dynamic field control (Létourneau et al. 2018)

Reference Dose Measurement Reference dose measurement assesses whether the radiation dose produced by the device is appropriately delivered to a specific target area. The LINAC's reference dose is measured along a specific depth across a defined field, confirming the accuracy of the dose output at the reference point.

Dose Output Calibration Dose output calibration ensures that the radiation doses produced by LINAC align with the doses determined during treatment planning. This process aims to determine the LINAC's capability to generate doses accurately, ensuring the safe and precise application of radiotherapy treatments.

Isocenter Dose Measurements Isocenter dose measurements are taken at the LINAC's isocenter point, corresponding to the focal point in the treatment field. These measurements are crucial for evaluating the dose distribution at the isocenter point and verifying the accuracy of treatment plans. They play a critical role in patient safety and treatment effectiveness.

Accuracy of the Irradiation Field

The accuracy of the irradiation field is assessed through jaw and multileaf collimator (MLC) control. Jaw and MLC positions are evaluated to ensure they conform to predefined values.

Beam Profile Control

Beam profile control involves checking the homogeneity and uniformity of the beam. Profile measurements are used to identify abnormalities in the beam's diameter and intensity.

Dynamic Field Control

Dynamic field control assesses the accuracy of dose output when using dynamic or moving fields during treatments. This is essential for determining whether the LINAC delivers accurate doses to moving targets during treatment.

Additional Controls

High voltage and current components must also undergo regular checks to ensure proper functioning at specified energy levels. Field dosimetry is performed to verify the dose in the beam field, commonly using ion chambers. Ion chambers are employed to confirm that the dose is delivered uniformly to the targeted areas. Quality controls for imaging systems that serve as references for RT should be conducted regularly to ensure accurate target positioning. The image quality, accuracy of treatment plans, and precision of patient positioning must be assessed. Controls for accessories used in the LINAC, as well as other equipment connected to it, should also be performed regularly. These controls are crucial for maintaining the correct position of the patient during treatment (Létourneau et al. 2018).

Regular controls ensure that the devices are functioning correctly and that treatment plans are implemented safely and effectively. The quality control process is carried out according to protocols established in accordance with national and international standards. The regularity of these controls is critical for the safety and effectiveness of the radiotherapy process.

Quality Control of Simulation and Imaging Devices

Simulation and imaging devices are essential components in radiotherapy preparation, providing detailed information for treatment planning. The main simulation and imaging devices include Computed Tomography (CT) Simulation, Magnetic Resonance Imaging (MRI), Positron Emission Tomography/Computed Tomography (PET/CT), and ultrasound devices.

Computed Tomography Simulation

CT simulation devices are crucial for detailed imaging of a patient's anatomical structures, aiding in the creation of radiotherapy plans. Quality control for CT simulation devices involves checking the accuracy of the device's calibration and ensuring the proper visualization of the patient's anatomical structures. Field numbers for Hounsfield units in CT numbers of water-equivalent materials must be verified against specified reference values. Additionally, the functionality of the device, including bed movement, scanning speed, and dose acquisition features, should be regularly checked (Stoel et al. 2008).

Magnetic Resonance Imaging

MRI is used in radiotherapy to visualize detailed anatomical structures and lesions. Quality control for MRI devices involves evaluating image quality regularly. MRI images should provide clear, sharp, and accurate anatomical information. Tests should be conducted for the strength and homogeneity of the magnetic field. The calibration of radiofrequency coils and other accessories is essential for accurate signal reception and functioning within a homogeneous magnetic field. The quality of MR signals is calibrated to ensure accurate magnetization and signal acquisition. Software updates for MRI devices are performed regularly, and the environmental conditions of the device, such as temperature and humidity, are monitored to ensure proper functionality (Bezin et al. 2015).

Positron Emission Tomography/Computed Tomography (PET/CT)

PET/CT devices combine positron emission tomography and computed tomography features to provide detailed anatomical and metabolic information. Quality control processes for PET/CT devices include assessing hardware, software, and imaging performance. CT quality is checked for factors such as resolution, contrast, dose, and homogeneity. PET sections measure metabolic activity using radiopharmaceuticals, and the quality of PET images is evaluated for resolution, sensitivity, and radiopharmaceutical distribution. The quality of obtained PET and CT images is assessed for contrast, resolution, homogeneity, and artifact control. The operating parameters and imaging protocols of the device should be regularly checked and updated (Somer, Pike, and Marsden 2012).

Ultrasonography

In radiation therapy, ultrasound devices are commonly used to visualize the patient's anatomical structures and tumors during the treatment planning. Ultrasound, an imaging technique, utilizes high-frequency sound waves to visualize reflections of tissues within the body. These images provide crucial information for treatment planning and target definition before the actual treatment. The frequency settings of ultrasound devices should be regularly checked, as operating at the correct frequency influences image resolution and penetration depth. Calibration of the device is conducted to ensure accurate measurement of ultrasound signals, a critical aspect for providing precise anatomical information. Contrast and resolution of images should be monitored to accurately visualize anatomical structures and identify tumors. Image artifacts, such as false reflections or distortions, may occur, making interpretation difficult; hence, regular control processes are necessary. The quality of the gel and probe used during ultrasound should also be verified for proper acoustic transmission and imaging. Regular checks and updates of device operating parameters and imaging protocols ensure accurate operation and compliance with contemporary techniques (Tome et al. 2002).

Additionally, additional imaging components used during radiation therapy are available, known as Image-Guided Radiation Therapy (IGRT) systems. IGRT systems are employed to verify patient positioning, and their accuracy should be regularly assessed. The simulation table, ensuring accurate movement towards the beam target, and laser equipment, crucial for precise treatment delivery, also require consistent evaluation. Laser beams used for defining the treatment area must be accurately targeted and regularly inspected.

Quality control processes are determined based on each device's specific features and the manufacturer's recommendations. Implementing appropriate quality control protocols ensures the acquisition of accurate and reliable images and the accurate formulation of treatment plans, contributing to the safe and effective management of the treatment process.

Treatment Planning Systems

Treatment planning systems are platforms where pre-treatment radiation therapy plans are developed. Beam data obtained from linear accelerator devices or other radiation therapy devices are loaded into these systems. Data from imaging devices are transferred to these systems in DICOM format. Treatment planning systems perform calculations based on this data to create a radiation therapy plan. Regular checks of treatment plans are essential to ensure the delivery of the appropriate dose to targeted tumor areas without harming normal tissues. Quality control of treatment planning involves evaluating the accuracy and suitability of dosimetric plans to be used during radiation therapy treatment (Anjum et al. 2017)

Basic steps for treatment planning quality control include the verification of patient and imaging information. Patient information must be accurate and complete, including identity details, dates, and other critical patient data. Imaging information (CT, MRI, PET, etc.) must be verified for accurate referencing and target definition. Tumor targets and normal tissues must be accurately defined, relying on clinical and imaging data. Advanced imaging methods may be employed when necessary to identify tumors, normal tissues, and organs at risk. The accuracy of dose calculation algorithms must be checked for dose calculation and dosimetric parameter control. This assessment evaluates the reliability of dose maps and dosimetric parameters. The treatment field must accurately encompass the tumor target, delivering minimal dose to normal tissues. Dose distribution must align with the planned target doses, and patient-specific quality controls are performed to verify the congruence of planned and targeted doses. After passing quality control, the implemented plan is checked for accurate positioning using patient positioning devices. IGRT systems, used to verify patient positioning, must undergo regular accuracy evaluations. These steps contribute to ensuring the reliability and accuracy of treatment planning. Quality control is regularly performed to detect errors in the radiation therapy process, enhance patient safety, and optimize treatment effectiveness. All measurements and controls must comply with international protocols published by organizations such as the American Society for Radiation Oncology (ASTRO), European Society for Radiotherapy and Oncology (ESTRO), and American Association of Physicists in Medicine (AAPM) (Palmans et al. 2018).

Data Backup and Information Flow Control

Information flow and data backup are crucial for monitoring patient treatment. Regular backup of patient treatment information, dosimetry plans, and other critical information, along with verifying the accuracy of information flow, is part of quality control. This control process aims to ensure the security and integrity of patient information used in the radiation therapy process. Essential steps for data backup and information flow quality control include daily backups of patient information, treatment plans, dosimetric data, and other critical information. Backup processes include the control of backup devices and media types. The integrity of backed-up data is regularly checked. In case of any damage or deficiencies in data files, swift intervention is necessary. Database integrity and relationships are reviewed. Security walls and access controls are regularly implemented to ensure information flow security. Security walls are installed to prevent unauthorized access to the system. Information flow and integration processes between different systems are regularly maintained. Ensuring smooth information flow among different devices, software, and information systems used in radiation therapy is crucial. Software and technological updates for data management and backup systems are regularly monitored. The integration and compatibility of updates with the system must be ensured. Backup strategies are reviewed based on current needs and standards, and data recovery processes are regularly tested. Emergency recovery plans and processes are established for any unforeseen circumstances, including equipment failures, natural disasters, or cyber-attacks. Emergency plans are regularly reviewed and updated to minimize information loss (Moran et al. 2011).

Quality Controls are applied to ensure the security, integrity, and accuracy of information used in radiation therapy. This control process holds critical importance in ensuring that patient data is safe and accessible. Additionally, personnel training and information updates in radiation therapy are integral parts of quality control. Training and quality assurance programs in radiation therapy are critically important to ensure that radiation therapy applications are conducted safely, effectively, and in compliance with standards. Personnel training programs should include basic training programs, professional development, and training on new technologies. Basic training programs for novice radiation therapy personnel should cover principles of radiation therapy, device usage, dosimetry, patient positioning, and safety topics. Radiation therapists should be encouraged to participate in regular continuous education and development programs to keep their knowledge and skills up to date. Special training programs should be organized when new devices and technologies are introduced. Radiation therapy staff should be regularly trained, and they should have up-to-date information (Moran et al. 2011).

Quality Control Methods

Radiation therapy treatment devices should be regularly calibrated and maintained to ensure the accurate application of doses, a critical aspect for patient safety. Dosimetric measurements and device controls are performed to verify that treatment doses are accurately calculated and applied. Auxiliary imaging methods like IGRT devices are regularly checked to ensure accurate patient targeting. Treatment planning processes are assessed with quality control protocols to confirm the accurate identification of tumor targets and normal tissues. Patient positioning devices and systems are checked to ensure accurate positioning during treatment (Xing et al. 2006).

Various quality control methods are employed for RT devices and components. These tests, including daily, weekly, or monthly routine checks, are conducted to ensure that devices function properly, and treatment processes adhere to standards. Performance tests for treatment devices and dosimetric systems are conducted using various phantoms. These measurements follow specific quality control protocols. These protocols are determined and applied in accordance with national and international standards. All conducted quality control activities are regularly recorded and reported.

Although these programs and quality control methods are performed according to national and international protocols, each application can be customized according to the needs and practices of a specific institution. Quality control processes assist the radiation therapy team in continuously adapting to evolving standards and technologies.

Dosimetric Equipments

Dosimeters measure the radiation dose administered to a patient. It is crucial to ensure the accurate operation and regular calibration of these devices. Field Dosimeters and Ion Chambers are employed to verify the delivery of precise doses during treatment. Dosimetric controls offer a preventive approach to detect and rectify potential errors in the radiotherapy process, thereby enhancing patient safety and maximizing treatment effectiveness. Radiotherapy centers develop quality control programs in accordance with national and international standards, regularly reviewing these programs. Quality control of dosimetric devices ensures the accurate and reliable delivery of doses in radiotherapy applications.

Various detectors are used for dosimetry in Radiotherapy (RT). These detectors evaluate energy response during the quality control process, checking whether the dose is accurately measured at specific energy levels. Ion Chambers, Diode detectors, Two-Dimensional Dosimeters, Diamond Detectors, Thermoluminescent Dosimeters (TLD), MOSFET detectors, and gel dosimeters are commonly used in RT dosimetry.

Ion Chambers

Ion chambers are crucial dosimetric devices for measuring radiation doses. Quality control assesses the calibration and accuracy of these chambers. Monitoring is conducted through calibration measurements at specific energy levels and target areas to ensure accurate dose measurement. An ion chamber is a dosimetric device consisting of a chamber filled with gas that measures ionization, determining the radiation dose. Ion chambers find applications in medical radiotherapy, nuclear medicine, industrial radiography, and nuclear energy (Saminathan et al. 2010).

There are three main types of ion chambers, with Cavity Ionization Chambers commonly used for high dose rates and values. Vented Ionization Chambers allow the release of gas from the ion chamber to the atmosphere or an enhanced chamber. Geiger-Muller Counters, based on the principle of ion chambers, are often used to measure low dose rates and are commonly referred to as counting devices. Cylindrical ion chambers are widely used in RT. These chambers consist of basic components such as a cavity, gas, and electrodes. The cavity is a chamber, usually cylindrical or box-shaped, filled with gas, typically inert gases like argon or helium. These gases initiate ionization processes by interacting with radiation. Electrodes within the ion chamber measure the electric current carried by ions formed in the gas. Calibration is necessary due to changes in air mass within the ion chamber volume, requiring pressure and temperature corrections.

Ion chamber measurements require accurate calibration and regular maintenance. Calibration is typically performed at specific time intervals and dose ranges. Ion chambers provide accurate measurements at high dose rates, have a broad dose range, and exhibit linear responses. However, disadvantages include their large, complex, and costly nature, limitations in measuring doses in air, water, or other media, and longer response times compared to other dosimetric devices (Gómez et al. 2022).

Diode Detectors

Diode detectors are devices used in radiotherapy to measure and monitor radiation doses. They are especially useful for measuring surface doses and verifying if radiation doses are delivered according to the treatment plan. Diodes generate electron-hole pairs when traversed by ionizing particles, creating an electric current during irradiation. The resulting current difference serves as the detector's signal and is connected to an electrometer for measurement. Diode detectors are compact, exhibit high sensitivity to radiation, and are independent of pressure and temperature changes. They find applications in small field dosimetry, such as IMRT and stereotactic treatments.

However, diodes have energy dependence and recombination characteristics, making them responsive to radiation damage. They also exhibit directional dependencies, with sensitivity varying up to 3% when irradiated perpendicular to the beam. Proper orientation and shielding are necessary to optimize their performance, especially in low-energy scattered photon conditions (Laub and Crilly 2014).

Two-dimensional Dosimeters

Two-dimensional dosimeters are devices that measure and track radiation doses in a specific plane. In radiotherapy, 2D arrays and film dosimeters are common among two-dimensional detectors. These detectors are used to verify treatment plan accuracy, optimize radiation doses, and ensure patient safety. 2D arrays consist of devices arranged in a matrix, with each detector measuring radiation doses and transmitting results to a computer. Flat panel detectors, such as electronic portal imaging detectors, measure radiation doses in a plane by using materials like amorphous silicon or brittle polycrystalline silicon, undergoing changes in properties when exposed to radiation. These changes are then used to determine the absorbed dose.

Film dosimeters determine the distribution of radiation dose. The quality control process assesses film calibration and accuracy. Film dosimetry measurements, made using a radiation-sensitive film, evaluate the accuracy of doses used in treatment planning periodically. Film dosimeters come in radiographic and radiochromic types.

Radiographic film dosimeters include conventional radiographic films used in medical imaging and examinations. They exhibit a wide dynamic dose range, low energy dependence, and directional sensitivity. However, they cause low-energy photon scatter due to their high atomic number materials. Film dosimeters have directional dependence.

Radiochromic film dosimetry incorporates a special gelatin layer that undergoes chemical changes when exposed to radiation. The layers consist of carbon, hydrogen, oxygen, and nitrogen. Color or optical density changes in the film are measured and analyzed to determine the radiation dose. Radiochromic films are independent of energy, exhibit dose-linear responses, and have high spatial resolution. They do not require post-irradiation processing, are insensitive to light, and offer high surface sensitivity. Radiochromic films are used in IMRT and stereotactic treatment plans for verification, MLC quality control, penumbra assessments, and surface dose measurements.

Advantages of film dosimetry include high resolution and sensitivity, the ability to determine dose distribution in 2D or 3D, quick measurement and evaluation due to advanced film technologies. However, disadvantages include long processing procedures, the need for special equipment and conditions for certain films, and the inability to reuse film dosimeters after initial use. Key factors in film dosimeter use include regular calibration, ensuring proper development conditions, and using accurate techniques to minimize measurement errors (Butson et al. n.d.).

Diamond Detectors

Diamond detectors are high-performance detectors used to measure radiation doses. Typically made from single-crystal diamond material, these detectors measure changes in the electrical properties of diamond crystals when exposed to radiation, determining the radiation dose. Diamond detectors, especially those made from high-purity single-crystal diamond material, are semiconductor devices. When exposed to radiation, they undergo changes in electrical conductivity due to the creation of electron-hole pairs in the diamond crystal. The resulting alterations are measured between electrodes located at the tip of the diamond detector, determining the radiation dose.

Diamond detectors are highly sensitive to radiation and offer high-precision measurements, providing reliable results even at low doses. The linear response of single-crystal diamond to radiation ensures high linearity. Diamond detectors provide accuracy and reliability, rapid response in dose measurement, longevity, and resistance to radiation damage. They exhibit a proportional response to absorbed dose rate, homogeneous directional dependence, and excellent spatial resolution, making them ideal for small field dosimetry with high dose gradients. Despite these advantages, diamond detectors have higher production and processing costs compared to other detectors, and the production and processing of single-crystal diamonds are challenging (Schirru et al. 2010).

Termoluminescent Dosimeters

Termoluminescent dosimeters (TLDs) are dosimeters that use thermoluminescent materials to measure radiation doses. Thermoluminescence is the phenomenon where the energy given to a crystal is re-emitted as light photons when the crystal is heated.

TLD dosimeters are made from chemical substances such as LiF (Mg, Ti), Li2B4O7, CaSO4, and CaF2. The most commonly used TLD material is LiF (Lithium Fluoride). LiF crystals, when exposed to radiation, exhibit thermoluminescent light emission when heated to a specific temperature. Another commonly used TLD material is Calcium Sulfate ($CaSO_4$), which is sensitive to alpha, beta, and gamma radiations. Magnesium Fluoride (MgF_2), another material, is sensitive to ultraviolet (UV) radiation. TLDs are typically used in the form of rods (cylinders) or chips (squares) and can also be found in powder form.

When exposed to radiation, the electrons of atoms inside the crystal are captured by traps. Upon heating the crystals, the electrons freed from the traps emit visible light of equal energy between two energy levels. The intensity of the emitted light is proportional to the absorbed radiation dose by the crystal. The graphs of changes in emitted light intensity over temperature or time create glow curves. The total area under a glow curve corresponds to both the radiation absorbed by the crystal and the total light emitted due to the crystal's heating. TLD measurements require a reader device, consisting of a TLD oven that reveals the absorbed dose through heat, a photomultiplier tube, and a printer screen. TLDs are compact, exhibit a long measurement range, and provide dose-proportional responses. The detector's dose effect will be erased after the reading process. Each dose on the TLD will be read once, making TLDs preferred for skin dose and measurements at radiation field edges. Advantages of TLDs include high sensitivity, long-term stability, dose repeatability, and the ability to work over a wide dose range. However, disadvantages include long readout times and limited dose measurement capabilities in specific energy ranges (Lonski et al. 2014).

MOSFET Detectors

Metal-Oxide-Semiconductor Field-Effect Transistor (MOSFET) detectors are semiconductor-based detectors used for dosimetry, measuring radiation doses in radiotherapy applications. While MOSFET is a fundamental semiconductor component in transistor technology, it can measure radiation doses when utilized as a detector. MOSFET detectors are typically silicon-based and consist of a capacitor and a transistor. The transistor, a key part of the structure, includes a metal coating with an added insulating layer (oxide layer) electrically charged by the examined radiation effect. When the detector is exposed to radiation, ionization of atoms in the oxide layer occurs, affecting the transistor structure. Changes in the electrical properties of the transistor due to radiation-induced alterations in the oxide layer enable the reading of the transistor's characteristics and the determination of radiation dose. MOSFET detectors respond rapidly to radiation, offering high resolution even at low doses and the ability to measure radiation doses inside a patient during treatment. However, drawbacks include being single-use, not reusable after calibration, sensitivity to operating temperatures, and direct impact from temperature changes (Kohno et al. 2008).

Gel Dosimetry

Gel dosimetry is a dosimetric technique used to achieve high dose sensitivity. In this method, a gel material is employed, and the chemical changes within the gel, measured when exposed to radiation, provide dose information. To ensure alignment between planned and measured doses, measurements taken during gel dosimetry use are regularly monitored. Gel dosimetry has various types, including Normoxic Polymer Gel Dosimetry, Ferrous Sulfate Gel Dosimetry, and Fricke Gel Dosimetry (Farhood et al. 2018).

Normoxic Polymer Gel Dosimetry involves a gel that measures changes in dose when exposed to radiation. It typically operates in an oxygen-rich environment. Ferrous Sulfate Gel Dosimetry uses a gel containing ferrous sulfate. Changes occur in the gel due to interactions between iron ions when exposed to radiation. Fricke Gel Dosimetry uses a gel containing radioactive iron in water. Reaction occurs among iron ions when exposed to radiation, and changes are measured to determine the dose. The gel is prepared by mixing predetermined materials, usually including water, gelatin, food coloring, and radiation-sensitive materials. The prepared gel is exposed to radiation, which may occur during radiotherapy treatment or in a laboratory setting with a specific dosage applied (Farhood et al. 2018). Chemical changes in the gel due to radiation exposure are analyzed. These changes, often measured using specialized analysis techniques like magnetic resonance imaging or optical methods, are converted into radiation dose. Advantages of gel dosimetry include the ability to measure 3D dose distributions, high resolution and sensitivity, and the acquisition of dosimetric data in real-time or shortly afterward. Drawbacks include the time-consuming nature of the process, requiring more complex analyses in a laboratory setting. Factors such as the chemical stability and reproducibility of the gel need attention in gel dosimetry, making it a significant dosimetric technique, especially in radiotherapy applications for treatment planning and dose control (Atiq et al. 2017).

Conclusion

Quality control methods in Radiotherapy (RT) are employed to ensure accurate and reliable application throughout every stage of the treatment process. These controls encompass processes from treatment planning to dose application and patient monitoring. The necessity of quality control methods is primarily related to ensuring patient safety and maximizing treatment effectiveness.

The aim of Radiotherapy quality control is to ensure that the correct doses are accurately directed to the appropriate target. Incorrect dose application or misdirection of the target to the wrong cells can lead to severe health issues. Therefore, quality control methods, including treatment planning, dosimetry, the performance of radiotherapy devices, patient position control, and imaging, should be utilized. It is essential to regularly maintain radiotherapy equipment during the quality control process, detect equipment malfunctions early, and make corrections. This ensures that the devices consistently operate accurately and reliably. Radiotherapy devices are complex and delicate machines, emphasizing the significant importance of regular maintenance and quality control.

In conclusion, Radiotherapy quality control methods are of critical importance to ensure patient safety, enhance treatment success, and sustain the accurate operation of equipment. These controls, by providing consistency and accuracy at every stage of the treatment process, contribute to helping patients achieve the best clinical outcomes.

References

Anjum, Rahil, C Varatharaj, M Ravikumar, K M Ganesh, S Sathiyan, B Shwetha, Masahiko Okumura, et al. 2017. “Intensity modulated radiotherapy plan verification for different dose rates and different grid sizes using fluence measurement reduction method of the skin surface dose in megavoltage photon radiotherapy verification of intensity modulated radiation thera.” *Gy for the Journal of Medical Physics*. Vol. 42.

Atiq, M, A Atiq, SA Buzdar - Pakistan Journal of Medical Research, and undefined 2017. 2017. “Gel Dosimeters for Radiotherapy: An Introductory Review.” *Researchgate.Net* 56 (3). https://www.researchgate.net/profile/Atia-Atiq/publication/320249700_Gel_Dosimeters_for_Radiotherapy_An_Introductory_Review/links/59d77f860f7e9b42a6b0a406/Gel-Dosimeters-for-Radiotherapy-An-Introductory-Review.pdf.

Bezin, Jérémi V, Rodrigue S Allodji, Jean-Pierre Mège, al -, Maria A Schmidt, and Geoffrey S Payne. 2015. “Radiotherapy Planning Using MRI.” *Iopscience.Iop.Org* 60. https://doi.org/10.1088/0031-9155/60/22/R323.

Butson, MJ, KN Peter, T Cheung, P Metcalfe - Materials Science and, and undefined 2003. n.d. “Radiochromic Film for Medical Radiation Dosimetry.” *Elsevier*. Accessed December 18, 2023. https://doi.org/10.1016/S0927-796X(03)00034-2.

Farhood, B, G Geraily, SMM Abtahi - Applied Radiation and Isotopes, and undefined 2019. 2018. “A Systematic Review of Clinical Applications of Polymer Gel Dosimeters in Radiotherapy.” *Elsevier*. https://doi.org/10.1016/j.apradiso.2018.08.018.

Gómez, Faustino, Diego M Gonzalez-Castaño, Nicolás Gómez Fernández, Juan Pardo-Montero, Andreas Schüller, Alessia Gasparini, Verdi Vanreusel, et al. 2022. “Development of an Ultra-thin Parallel Plate Ionization Chamber for Dosimetry in FLASH Radiotherapy.” *Wiley Online Library* 49 (7): 4705–14. https://doi.org/10.1002/mp.15668.

Kohno, Ryosuke, Motohiro Kawashima, A E Eriko, Hirano Ae, Teiji Nishio, A E Tomoko, Miyagishi Ae, et al. 2008. “Dosimetric Evaluation of a MOSFET Detector for Clinical Application in Photon Therapy.” *Springer* 1 (1): 55–61. https://doi.org/10.1007/s12194-007-0007-9.

Laub, Wolfram U., and Richard Crilly. 2014. “Clinical Radiation Therapy Measurements with a New Commercial Synthetic Single Crystal Diamond Detector.” *Journal of Applied Clinical Medical Physics* 15 (6): 92–102. https://doi.org/10.1120/JACMP.V15I6.4890.

Létourneau, Daniel, Harald Keller, Nathan Becker, Md Nurul Amin, Bernhard Norrlinger, and David A. Jaffray. 2018. “Quality Control Methods for Linear Accelerator Radiation and Mechanical Axes Alignment.” *Medical Physics* 45 (6): 2388–98. https://doi.org/10.1002/mp.12910.

Lonski, P., M. L. Taylor, R. D. Franich, and T. Kron. 2014. "A Collimated Detection System for Assessing Leakage Dose from Medical Linear Accelerators at the Patient Plane." *Australasian Physical and Engineering Sciences in Medicine* 37 (1): 15–23. https://doi.org/10.1007/s13246-013-0235-8.

Moran, Jean M., Melanie Dempsey, Avraham Eisbruch, Benedick A. Fraass, James M. Galvin, Geoffrey S. Ibbott, and Lawrence B. Marks. 2011. "Safety Considerations for IMRT: Executive Summary." *Medical Physics* 38 (9): 5067–72. https://doi.org/10.1118/1.3600524.

Palmans, Hugo, Pedro Andreo, M. Saiful Huq, Jan Seuntjens, Karen E. Christaki, and Ahmed Meghzifene. 2018. "Dosimetry of Small Static Fields Used in External Photon Beam Radiotherapy: Summary of TRS-483, the IAEA–AAPM International Code of Practice for Reference and Relative Dose Determination." *Medical Physics* 45 (11): e1123–45. https://doi.org/10.1002/MP.13208.

Saminathan, Sathiyan, Ravikumar Manickan, Varatharaj Chandraraj, and Sanjay S Supe. 2010. "Dosimetric Study of 2D Ion Chamber Array Matrix for the Modern Radiotherapy Treatment Verification." *Wiley Online Library* 11 (2): 116–27. https://doi.org/10.1120/jacmp.v11i2.3076.

Schirru, F, K Kisielewicz, … T Nowak - Journal of Physics D, and undefined 2010. 2010. "Single Crystal Diamond Detector for Radiotherapy." *Iopscience.Iop.Org*, no. 26: 265101. https://doi.org/10.1088/0022-3727/43/26/265101ï.

Somer, E. J., L. C. Pike, and Paul K. Marsden. 2012. "Recommendations for the Use of PET and PET-CT for Radiotherapy Planning in Research Projects." *British Journal of Radiology* 85 (1016). https://doi.org/10.1259/BJR/46048428.

Sonke, Jan Jakob, Marianne Aznar, and Coen Rasch. 2019. "Adaptive Radiotherapy for Anatomical Changes." *Seminars in Radiation Oncology*. https://doi.org/10.1016/j.semradonc.2019.02.007.

Stoel, Berend C, Fred Bode, Alexis Rames, Sherif Soliman, Johan H C Reiber, and Jan Stolk. 2008. "Quality Control in Longitudinal Studies with Computed Tomographic Densitometry of the Lungs." *Atsjournals.Org* 5 (9): 929–33. https://doi.org/10.1513/pats.200804-039QC.

Tome, Wolfgang Axel, Wolfgang A Tomé, Sanford L Meeks, Nigel P Orton, Lionel G Bouchet, and Francis J Bova. 2002. "Commissioning and Quality Assurance of an Optically Guided Three-dimensional Ultrasound Target Localization System for Radiotherapy." *Wiley Online Library* 29 (8): 1781–88. https://doi.org/10.1118/1.1494835.

Xing, Lei, Brian Thorndyke, Eduard Schreibmann, Yong Yang, Tian Fang Li, Gwe Ya Kim, Gary Luxton, and Albert Koong. 2006. "Overview of Image-Guided Radiation Therapy." *Medical Dosimetry* 31 (2): 91–112. https://doi.org/10.1016/j.meddos.2005.12.004.