

An Overview of Advanced Radiotherapy Techniques in Cancer Treatment

Rahul Rai¹ and Krishna Kumar Singh²

¹Ph.D. Research Scholar, Department of Physics, F.S. University, Shikohabad, Uttar Pradesh, INDIA.

²Assistant Professor, Department of Physics, F.S. University, Shikohabad, Uttar Pradesh, INDIA.

¹Corresponding Author: happyrahulrai@gmail.com



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ABSTRACT

In the past few decades, radiotherapy has changed a lot. In cancer care, new treatment methods have improved accuracy, effectiveness, and patient safety. Modern radiotherapy aims to limit exposure to healthy areas while delivering high doses of radiation to tumor tissues. Techniques like IMRT and VMAT use computer-controlled adjustments to deliver accurate dose distributions. Compared to older methods, these techniques target tumors better and reduce side effects from treatment. IGRT involves real-time imaging technologies that boost treatment accuracy. This helps confirm the tumor's location and patient positioning both before and during treatment. It also considers changes in anatomy during therapy and reduces setup errors. Techniques like SRS and SBRT are especially helpful for small or well-defined tumors because they can deliver very high radiation doses in fewer sessions with millimeter-level accuracy. Proton therapy and other particle therapies offer special physical benefits due to the Bragg peak effect. This helps protect nearby healthy tissues while delivering the right amount of energy to the tumor. Tumors located near vital organs gain the most from these treatments. To improve treatment results, these innovative radiotherapy techniques combine precise imaging, planning tools, and delivery systems. These advancements are vital for enhancing patient quality of life and providing tailored cancer care by increasing tumor control rates and reducing side effects.

Keywords- Intensity-Modulated Radiotherapy, Volumetric Modulated Arc Therapy, Image-Guided Radiotherapy, Stereotactic Radiosurgery, Stereotactic Body Radiotherapy, Proton therapy.

I. INTRODUCTION

Radiotherapy or simply Radiation Therapy is a medical intervention employed in cancer treatment. The objective of radiotherapy is to employ high-energy radiation to eliminate cancer cells or regulate their proliferation. While aiming to eradicate cancer cells, Radiotherapy seeks to reduce harm to adjacent healthy tissues. The objectives of radiation include the destruction or control of cancer cell proliferation, reduction of tumor size, and alleviation or elimination of cancer symptoms (Jaffray et al., 2007).

Over the past few decades, there has been a significant change in the way that radiotherapy is delivered. Conventional radiotherapy, which used straightforward rectangular treatment fields, has given way to more conformal radiotherapy methods like

intensity modulated radiotherapy (IMRT), volumetric modulated arc therapy (VMAT), image guided radiotherapy (IGRT) and three-dimensional conformal radiotherapy (3DCRT). These modifications to radiotherapy delivery have resulted from efforts to increase the dose administered to tumor-bearing tissues and decrease radiation exposure to organs at risk (OARs), thereby increasing the radiation treatment's therapeutic ratio. The precise targeting of tumors while maximizing the preservation of normal tissues has been the primary objective of radiation therapy (Vikram et al., 2009).

There are two types of radiation therapy: internal and external. High-energy X-rays are applied to the tumor site from the outside during external radiotherapy. To target and treat cancerous cells or tumors, a machine for external radiotherapy creates high-energy radiation beams that are directed externally at the patient's body.

The radiation source is positioned inside the tumor or bodily cavities during internal radiotherapy, also known as brachytherapy (Ragde et al., 2000). Imaging is the first step in the radiotherapy procedure. First, the patient's CT (Computerized Tomography) images are acquired in DICOM format.

After that, the CT scan is imported into the treatment planning system. To shape the target volume, the images that are imported into the treatment planning system are brought together with positron emission tomography (PET) and/or magnetic resonance imaging (MRI) images. For radiotherapy to be both safe and effective, careful planning is necessary (Schneider et al., 1996).

With the help of these images, the planning target volume (PTV), which consists of the gross tumor volume (GTV) and regions of microscopic spread (clinical target volume, or CTV) and a margin surrounding it to take into consideration both random and systematic errors as well as changes in physiological organs that take place throughout the course of treatment planning and administration is contoured by radiation oncologist. Thereafter final treatment planning of patient is done by a medical physicist (D. Jones, 1994). Delivering a radical dose to the PTV using advance radiotherapy treatment techniques causes a minimal dose to the OARs. Several tumor sites, including the head and neck, prostate, and lung, have strong evidence that dose escalation and/or modified fractionation lead to better results (Peeters et al., 2006; Urbano et al., 2007).

The advancements in radiotherapy technology over the last ten years have been tremendous. An overview of recent advancements in radiotherapy technology is provided in this study.

1.1 Three-dimensional conformal radiotherapy (3DCRT)

3DCRT is the first conformal treatment planning method that uses multiple cross-firing with precisely shaped fixed fields and 3D treatment planning. The patient must be immobilized and positioned in the treatment position during the CT scan in order to perform 3DCRT. Images with slices that are 1 to 3 mm thick are used to define GTV, CTV, OAR, and PTV with a daily set-up errors margin. In order to determine the type of energy, the number of beams with their angles and directions, the collimator angle, and how to shape the target volume with multileaf collimators (MLCs), a medical physicist uses a treatment planning system. Dose volume histograms and isodose curves with protocols are used to assess the dose that the target and normal tissues received. Following approval of the plan, matching planning and treatment imaging are carried out as part of the setup procedure (Rosenman et al., 1989).

1.2 Intensity modulated radiotherapy (IMRT)

IMRT is a sophisticated method for conformal therapy and three-dimensional treatment planning. It has the capacity to create concavities in radiation treatment volumes and maximizes the delivery of radiation to

volumes with irregular shapes. Three-dimensional conformal radiation therapy, which sought to increase the precision of radiation delivery, is where IMRT first emerged (Ezzell et al., 2003). IMRT is based on inverse treatment planning, where the desired dose distribution is determined, and the treatment planning system calculates the optimal intensity pattern for each beam to achieve this distribution. This method differs from traditional radiation therapy, which depends on forward planning (Cho, 2018).

Every treatment field is separated into several beams with varying intensities by IMRT. An ideal dose distribution that fits the tumor's shape is produced by varying the intensity of these beams. As crucial as the IMRT planning is the precision of the dose given to the patient. The target volume and critical organs' objectives and priority values are entered into the system to create a reverse optimization plan when planning in IMRT. Moreover, the multicriteria optimization algorithm present in certain treatment planning systems can be used to create an IMRT plan (KAVAK et al., 2022).

Inside the head of a treatment device are lead plates called multileaf collimators (MLCs), which are made up of several thin leaves. MLCs, which can modify the radiation field during treatment, are a major component of IMRT. This technology improves dose conformity by enabling quick and accurate radiation intensity modulation.

1.3 Volumetric modulated arc therapy (VMAT)

Volumetric modulated arc therapy uses a single 360-degree rotation of the linear accelerator gantry to deliver a precisely sculpted 3D dose distribution (Otto, 2008). Three parameters are simultaneously changed during treatment by a treatment planning algorithm, which makes it possible:

(1) delivery dose rate, (2) gantry rotation speed, and (3) treatment aperture shape based on multileaf collimator leaf movement.

Using one or more arcs, VMAT treatments can be administered precisely and successfully. The main VMAT has the benefit of being able to treat the patient considerably more quickly than fixed gantry IMRT (Surucu et al., 2011).

1.4 Image guided radiotherapy (IGRT)

Accurate target localization is the core idea behind IGRT. IGRT guarantees precise tumor or target volume positioning and real-time monitoring during radiation delivery, not just during treatment planning. This enables modifications to be made in response to the target's size, shape, and position at any given time. IGRT is especially useful in managing anatomical changes brought on by things like weight loss, tumor regression, or organ motion because it allows for flexible treatment planning that can take into account modifications in the patient's anatomy or tumor response during treatment (Bissonnette et al., 2012).

IGRT is a helpful tool that can identify and fix both systematic and random errors that happen when

administering treatment. Digitally reconstructed radiographs and portal imaging are the most basic types of IGRT. Instead of using patient-oriented positioning, more sophisticated IGRT techniques that enable target-oriented positioning are being implemented in clinical practice. To improve tumor delineation and/or adjust for intra- and/or inter-fraction motion during radiation therapy, image guidance can be employed.

1.5 Stereotactic Radiosurgery (SRS) and Stereotactic Body Radiation Therapy (SBRT)

A type of radiation therapy called stereotactic radiosurgery (SRS) is used to treat brain tumors and functional abnormalities. Compared to traditional treatment, SRS treatment applies a higher radiation dose in fewer fractions, which helps better preserve healthy tissue (Combs et al., 2005). Stereotactic body radiation therapy (SBRT) is the term used to describe its application in the treatment of body tumors (Okunieff et al., 2006). In radiation oncology, SRS and SBRT can be regarded as innovative therapeutic approaches.

A single high dose is usually administered in a single session for SRS, but the SBRT concept enables the treatment of larger and more irregularly shaped tumors by extending it to multiple fractions (Vergalasova et al., 2019). Many researches have demonstrated that SRS and SBRT improve quality of life, increase survival rates, decrease side effects, and have high local control rates.

1.6 Adaptive Radiation Therapy

Even though the course of radiation therapy takes several fractions and weeks to finish, dosimetric variation at organs, patient weight loss, and target size and shape, such as early tumor shrinkage, and variations in OAR that lead to variations in treatment accuracy and dose distribution. Using image guidance, dose verification, and plan adaptation, the adaptive radiotherapy principle is used to quantify treatment variations and match the planned dose distribution with the final delivered dose distribution. This adaptation improves tumor control and reduces late morbidity (Yan, 2010).

Because adaptive radiation therapy is dynamic, it can adjust to changes in tumor size and location, increasing treatment efficacy and accuracy. It reduces the amount of radiation that reaches healthy tissues, which lowers side effects associated with treatment and enhancing the patient's quality of life.

1.7 Brachytherapy

Brachytherapy is an internal radiation therapy that delivers a high dose of radiation locally by positioning a radioactive source inside or close to the tumor using applicators. Brachytherapy is now a precise and dependable treatment option for gynecologic cancers, prostate cancers, breast cancers, skin cancers, sarcomas, and ocular diseases thanks to advancements in 3D imaging and conformal radiotherapy for optimizing the dose distribution (Nag, 2004; Thomadsen et al., 2014).

1.8 Hypofractionation

Conventional radiation therapy regimens usually entail administering radiation therapy doses five days a week. A change from conventional radiation treatment methods is hypofractionation.

In contrast to administering smaller doses of radiation over an extended period of time, hypofractionation entails administering larger doses of radiation in fewer treatment sessions. This method benefits both patients in a number of ways. The most significant of these is the reduction of treatment duration while maintaining patient comfort (B. Jones et al., 2000). Studies indicate that this method can be just as successful as conventional radiation therapy, with the added benefit of requiring less time for treatment (Hegemann et al., 2014).

1.9 Proton Beam

Proton therapy is the most researched type of charged particle radiotherapy. It uses proton particles and, thanks to recent significant advancements in particle accelerator technology, can spare normal tissues far from the tumor target from incidental irradiation by stopping at a specific depth based on their initial energy (pristine Bragg peak). Since photon therapy delivery techniques have become more precise over the past few decades, proton therapy planning and delivery techniques are also developing for the treatment of tumors close to sensitive organs, including ocular, nasal, and skull-based tumors, as well as pediatric cases where harm to the surrounding tissues can have serious repercussions (Doyen et al., 2016; Holliday & Frank, 2014).

1.10 Artificial Intelligence (AI) in Radiation Therapy and Radiomics

A revolutionary paradigm shift in radiation therapy has resulted from the incorporation of radiomics and artificial intelligence (AI). Radiomics is a recently developed area of medical imaging that is concerned with obtaining high-dimensional information from radiological images (Lohmann et al., 2020).

Radiomics plays a significant role in radiation therapy. Radiomics makes it possible to forecast how a tumor will react to radiation treatment. Radiation oncologists can better understand tumor behavior and customize treatment regimens to the unique features of each tumor by utilizing radiomics features to analyze pretreatment imaging data. Radiomics can be used to assess treatment response both during and after radiation therapy. Radiomics analysis can give early warning signs of treatment efficacy or the need for treatment modification by tracking changes in tumor tissue and shape over time (Arimura et al., 2019).

Ultimately, by offering more individualized and accurate treatment options, radiomics and artificial intelligence hold the potential to completely transform radiation therapy.

II. SUMMARY AND CONCLUSION

Every stage of radiotherapy incorporates technological advancements such as simulation, MLC modulation of radiation beams, and enhanced inverse treatment through the integration of imaging and computer software. High tumor control rates and overall results were achieved through the management of highly customized dose distribution with maximum preservation of the surrounding structures through planning, image guidance, AI, adaptive radiotherapy, and stereotactic treatments.

These sophisticated radiotherapy treatment methods seek to minimize side effects and enhance overall treatment results by striking the ideal balance between tumor control and the preservation of healthy tissue. Using a multidisciplinary approach that includes medical physicists and radiation oncologists, the technique selection is based on the particular cancer type, stage, location, and patient characteristics.

These developments frequently lead to reduced treatment durations, fewer side effects, and improved capacity to carry out everyday tasks while undergoing therapy. Even in complicated or previously incurable cases, they give clinicians helpful tools to strike a balance between safety and efficacy. Crucially, the integration of imaging, computing power, and novel biological concepts demonstrates that radiotherapy is a dynamic field that continues to advance in tandem with scientific discoveries. Ultimately, modern radiotherapy is not just about delivering radiation more accurately; it is about providing hope more responsibly. As innovation continues, the focus remains clear: to cure when possible, to control when necessary, and always to care.

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