

Technical Characteristics and Clinical Applications of Contemporary Radiotherapy Equipment

Chu Fei^{1*}

¹ Elekta Instrument (Shanghai) Ltd., Beijing Branch, Beijing, China

Email Address

728606556@qq.com (Chu Fei)

*Correspondence: 728606556@qq.com

Received: 2 July 2024; Accepted: 20 July 2024; Published: 30 July 2024

Abstract:

This paper reviews the technical characteristics and clinical importance of various contemporary radiotherapy equipment. It first introduces the basic principles and technical background of radiotherapy, including the mechanisms by which radiation affects tumor cells. And then, it discusses common types of radiotherapy equipment such as linear accelerators, radionuclide therapy machines, and hadron therapy equipment, analyzing their working principles and technical features. The paper further compares these devices in terms of technical characteristics and clinical application effects. Finally, it explores future trends in radiotherapy technology, including technological innovations and challenges, providing prospects for the future development of radiotherapy technology.

Keywords:

Radiotherapy Equipment, Linear Accelerator, Radionuclide Therapy Machine, Hadron Therapy

1. Introduction

Radiotherapy, a critical component of modern cancer treatment, uses high-energy radiation to destroy tumor cells and plays a vital role in clinical practice. With continuous technological advances and equipment innovation, various types of radiotherapy equipment have significantly improved treatment effectiveness, reduced side effects, and expanded treatment indications. This paper systematically reviews the technical characteristics and clinical importance of contemporary radiotherapy equipment to provide comprehensive technical analysis and application guidance for medical professionals and researchers.

2. Fundamentals of Radiotherapy

2.1. Definition and Basic Principles of Radiotherapy

Radiotherapy is a treatment method that uses high-energy radiation, such as photon or particle beams, to destroy or inhibit the growth of cancer cells. The basic principle

involves ionizing radiation to directly damage the DNA of cancer cells or affect their normal cell division capabilities, thereby achieving tumor treatment. Radiotherapy can be curative, aiming to eliminate the tumor entirely, or palliative, aiming to relieve symptoms and improve the quality of life for patients with advanced cancer [1]. Its versatility makes it a cornerstone in the multidisciplinary approach to cancer treatment. Radiation acts on tissues in two main ways: direct and indirect. Direct action involves radiation interacting directly with DNA molecules within cancer cells, causing DNA strand breaks or gene mutations, which disrupts the cancer cells' ability to reproduce and repair, leading to cell death. Indirect action involves radiation generating chemical reactions with water molecules in the cells, producing harmful free radicals and other reactive oxygen species. These reactive molecules cause additional damage to cellular components, indirectly leading to the death of cancer cells. The choice and application of radiotherapy need to consider various factors, including the type and location of the tumor, the stage of cancer, the overall health status of the patient, and the expected effects and side effects of the treatment. Tumors located in sensitive areas or close to critical organs may require more precise delivery techniques to minimize damage to surrounding healthy tissues. With technological progress, the precision of radiotherapy equipment and the personalization of treatment plans have continuously improved. Advanced imaging techniques, such as CT, MRI, and PET scans, are now routinely used to delineate tumor boundaries accurately and monitor the tumor's response to treatment. Techniques like Intensity-Modulated Radiation Therapy (IMRT) and Volumetric Modulated Arc Therapy (VMAT) allow for more precise targeting of radiation doses, sparing healthy tissues while delivering higher doses to the tumor. Furthermore, advancements in radiotherapy have led to the development of stereotactic radiosurgery (SRS) and stereotactic body radiotherapy (SBRT), which deliver highly focused doses of radiation to small, well-defined tumors in a few treatment sessions. These techniques have shown significant promise in treating brain tumors, lung tumors, and other cancers with minimal invasiveness and reduced treatment times. In summary, radiotherapy's definition and basic principles revolve around using high-energy radiation to target and destroy cancer cells. The continuous evolution of radiotherapy technology and treatment planning has greatly enhanced the accuracy, effectiveness, and safety of this vital cancer treatment modality, offering patients more precise and personalized treatment options.

2.2. Development History of Radiotherapy

Radiotherapy as a significant treatment method in modern medicine can trace its development back to the early 20th century. Here are the main milestones and key technological advances in radiotherapy development:

- **Discovery and Experimental Stage:** The discovery of radiation and initial experiments laid the foundation for radiotherapy. In 1895, Wilhelm Röntgen discovered X-rays, which quickly found applications in the medical field, providing new possibilities for cancer treatment.
- **Early Treatment Practices:** Early radiotherapy equipment mainly included manually controlled X-ray generators used for treating superficial tumors and some deep tumors, focusing on the initial application of technology and exploration of treatment methods.
- **Development of Linear Accelerators:** The invention of linear accelerators (LINAC) in the late 1940s to 1950s marked a significant breakthrough in radiotherapy

equipment technology. LINACs provided higher energy and more precise radiation beams, significantly enhancing radiotherapy precision and effectiveness.

- Computer-Assisted Treatment Planning: With the development of computer technology, treatment planning and dose distribution in radiotherapy gradually shifted from manual to computer-assisted precise planning, greatly improving the personalization and predictability of treatment outcomes [2].

- Introduction of New Technologies: Recent years have seen increased application of advanced technologies like hadron therapy and radionuclide therapy, offering more effective and precise treatment options for specific tumor types.

The development history of radiotherapy not only witnessed the evolution from experimental stages to modern high-precision treatment technologies but also provided more treatment options and hope for cancer patients. Next, we will analyze common types of radiotherapy equipment and their clinical applications in detail.

2.3. Role of Radiotherapy in Cancer Treatment

Radiotherapy plays a crucial role in modern cancer treatment by precisely targeting tumor sites to kill or inhibit cancer cell growth, thereby achieving local disease control and potentially curing the cancer. The ability to target tumors with high precision makes radiotherapy an invaluable tool in the oncologist's arsenal, allowing for the treatment of a wide variety of cancers with differing levels of complexity and severity. For early-diagnosed tumors or those unsuitable for surgical removal, radiotherapy is often the preferred or auxiliary treatment. It significantly improves patient survival rates and quality of life by effectively reducing or eliminating tumor masses. In cases where tumors are detected early, radiotherapy can be used alone to cure the patient, eliminating the need for more invasive procedures. This non-invasive nature of radiotherapy, combined with its ability to target and destroy cancer cells with minimal damage to surrounding healthy tissues, makes it an attractive option for many patients and healthcare providers. Radiotherapy also plays an important role in preoperative and postoperative treatment. Preoperative (neoadjuvant) radiotherapy is used to shrink tumors before surgery, making them easier to remove and increasing the likelihood of a successful surgical outcome. Postoperative (adjuvant) radiotherapy aims to eliminate any residual cancer cells that may remain after surgery, thereby reducing the risk of recurrence and metastasis. This dual role in the surgical setting underscores the versatility and importance of radiotherapy in comprehensive cancer treatment plans. For advanced cancer patients, radiotherapy serves as a key palliative treatment. Palliative radiotherapy aims to reduce tumor size or alleviate pressure on surrounding tissues, thereby significantly easing symptoms and pain. This can greatly improve the quality of life for patients with advanced or metastatic cancers, helping them manage pain and other symptoms effectively [3]. By reducing the burden of cancer symptoms, palliative radiotherapy enables patients to maintain better functionality and comfort in their daily lives. Radiotherapy is increasingly used in multimodal treatment plans, often combined with chemotherapy, immunotherapy, and other treatments to enhance overall efficacy and reduce cancer cells' resistance to treatment. The integration of radiotherapy with other treatment modalities helps in attacking cancer cells from multiple angles, improving the chances of treatment success. For example, combining radiotherapy with chemotherapy (chemoradiotherapy) can enhance the sensitivity of cancer cells to radiation, leading to more effective tumor control. In summary, radiotherapy is not only a treatment

method but also an essential part of comprehensive cancer treatment. Its ability to precisely target tumors, reduce tumor burden, and alleviate symptoms makes it a cornerstone of modern oncology. With continuous technological advancements and optimized treatment strategies, radiotherapy's role and application prospects in cancer treatment will continue to expand and deepen. Future innovations in radiotherapy technology and techniques will likely further enhance its efficacy, safety, and accessibility, providing even better outcomes for cancer patients worldwide.

3. Common Types of Radiotherapy Equipment

3.1. Linear Accelerators (LINAC)

Linear accelerators (LINAC) are widely used in radiotherapy. They accelerate charged particles (usually electrons) to very high speeds and direct them to a target area, producing high-energy X-ray or electron beams. These beams can precisely target and irradiate tumor tissues to destroy cancer cell DNA and inhibit their growth. LINACs work on the principle of using radiofrequency accelerators and magnetic fields. Electrons are accelerated through a radiofrequency electric field and then directed to a specific target, such as a cancer lesion. LINACs provide highly personalized treatment plans, adjusting radiation doses and angles according to the patient's pathology and anatomical characteristics, minimizing damage to surrounding healthy tissues. Modern LINACs offer advanced treatment techniques such as Intensity-Modulated Radiation Therapy (IMRT), Volumetric Modulated Arc Therapy (VMAT), and respiratory gating. These technologies make LINACs highly effective for treating complex cases and targeting mobile tumors. Overall, LINACs play a key role in cancer treatment, providing high precision and personalized treatment plans that significantly enhance treatment outcomes and patient quality of life. Next, we will explore other common types of radiotherapy equipment and their specific clinical applications.

3.2. Radionuclide Therapy Machines

Radionuclide therapy machines utilize radioactive isotopes to treat cancer. This method is typically used for specific cancer types, especially thyroid cancer and bone metastases. In radionuclide therapy, patients receive drugs containing radioactive isotopes that selectively accumulate in tumor tissues. The radiation energy released by these isotopes directly acts on cancer cells, destroying their DNA structure or inhibiting their division capabilities. This method's advantage lies in its non-invasiveness, reducing the need for surgery and effectively controlling metastatic cancer. Common radionuclide therapies include Iodine-131 for thyroid cancer and Yttrium-90 for liver cancer. These treatments require precise dose calculations and treatment planning to ensure safety and effectiveness, making radionuclide therapy machines uniquely valuable, especially for cancers difficult to control through surgery or other methods. As technology advances and treatment strategies improve, radionuclide therapy machines will continue to expand their role in cancer treatment, providing patients with more options and hope [4].

3.3. Hadron Therapy Equipment

Hadron therapy equipment represents the cutting edge of radiotherapy technology, employing charged proton or heavy ion beams, such as carbon ions, to precisely target and irradiate tumor tissues. This advanced form of radiotherapy offers significant

advantages over traditional X-ray therapy, making it highly effective for treating various types of cancer. A key benefit of hadron therapy is the “Bragg peak” effect, where the proton or heavy ion beams deliver their maximum energy dose directly within the tumor tissue, sparing the surrounding healthy tissues from excessive radiation exposure. This characteristic enhances treatment precision and safety, minimizing side effects and improving patient outcomes. The ability to focus the radiation dose so precisely means that hadron therapy is particularly beneficial for tumors located near critical organs or those that are difficult to remove surgically. Hadron therapy is widely used to treat complex and large-volume tumors. Its high precision makes it especially suitable for pediatric and adolescent cancer patients, as it reduces the risk of long-term side effects and secondary cancers, which are crucial considerations for younger patients. The potential for fewer side effects and more targeted treatment makes hadron therapy an attractive option for these vulnerable groups. Despite the high cost and significant facility requirements associated with hadron therapy equipment, technological advancements and increasing accessibility are leading to its broader application in medical centers worldwide. The development of more compact and cost-effective systems is gradually making hadron therapy more accessible to a larger number of patients. Looking ahead, ongoing research and technological improvements are expected to further expand the role and impact of hadron therapy in cancer treatment. Innovations in beam delivery, imaging techniques, and patient positioning are likely to enhance the precision and effectiveness of hadron therapy even further [5]. Additionally, clinical trials and studies will continue to refine treatment protocols, ensuring that more patients can benefit from this advanced technology. In conclusion, hadron therapy equipment is a powerful tool in the fight against cancer, offering precise, effective treatment options for complex and challenging cases. As technological advancements continue to improve its accessibility and effectiveness, hadron therapy is poised to play an increasingly important role in the future of cancer treatment.

4. Comparative Analysis of Equipment Technical Characteristics

4.1. Linear Accelerators vs. Radionuclide Therapy Machines

Linear accelerators (LINAC) and radionuclide therapy machines are both crucial in radiotherapy. LINACs utilize high-energy electron or X-ray beams to directly irradiate tumor tissues, offering precise control over radiation doses and angles, which minimizes damage to surrounding healthy tissues. This makes LINACs suitable for complex and targeted treatments, such as Intensity-Modulated Radiation Therapy (IMRT) and Volumetric Modulated Arc Therapy (VMAT), allowing doctors to develop personalized treatment plans based on specific tumor morphology and location. Radionuclide therapy machines, on the other hand, treat cancer by injecting patients with drugs containing radioactive isotopes. These isotopes release radiation that targets tumor tissues, making this method ideal for certain cancer types like thyroid cancer and bone metastases due to its non-invasiveness and specificity. Radionuclide therapy machines offer the advantage of targeted radiation with minimal impact on surrounding tissues, reducing the need for surgery and discomfort during treatment. Both LINACs and radionuclide therapy machines have unique technical features and application advantages, allowing medical professionals to choose the most appropriate treatment based on the patient's specific condition and treatment goals. Continuous technological progress and treatment strategy improvement will further expand and deepen the role of these devices in cancer treatment.

4.2. Radionuclide Therapy Machines vs. Hadron Therapy Equipment

Radionuclide therapy machines and hadron therapy equipment represent two advanced technologies in the field of radiotherapy, each with significant differences. Radionuclide therapy machines use drugs containing radioactive isotopes to treat tumors, particularly suitable for specific cancer types like thyroid cancer and bone metastases. These drugs target and accumulate in tumor tissues, and the radiation energy released by the isotopes directly affects cancer cells. This non-invasive treatment is preferred for patients sensitive to surgery or unable to undergo surgery, with minimal side effects. Hadron therapy equipment, using charged proton or heavy ion beams, offers precise tumor tissue irradiation. The characteristic “Bragg peak” of these beams delivers maximum energy within the tumor while minimizing damage to surrounding tissues. This precision makes hadron therapy ideal for complex, large-volume tumors, especially those near critical organs or difficult to surgically remove. Radionuclide therapy focuses on targeted radiation effects of drugs, while hadron therapy emphasizes high precision and treatment effectiveness, particularly for protecting surrounding tissues. Medical professionals choose suitable equipment based on the patient’s condition, tumor type and location, and treatment goals to ensure optimal treatment outcomes and patient quality of life. As radiotherapy technology continues to advance, the application prospects of these devices will further expand and deepen [6].

5. Future Trends in Radiotherapy Technology

The future of radiotherapy technology will focus on improving treatment effectiveness, reducing side effects, and enhancing patient quality of life. Personalized treatment will be a major trend, with advancements in molecular biology and genetics enabling more precise predictions of tumor responses to radiation, allowing for customized treatment plans. Technological innovations will drive future developments, including more advanced linear accelerators (LINAC) integrating real-time imaging and pathological image analysis to enhance treatment accuracy and safety. The adoption of multimodal treatment strategies, such as Intensity-Modulated Radiation Therapy (IMRT), Volumetric Modulated Arc Therapy (VMAT), and hadron therapy, will further optimize tumor control and reduce post-treatment side effects. The development of biological dose modulation technology will focus more on individualized treatment by monitoring and adjusting radiation doses in real-time to minimize damage to surrounding tissues while ensuring effective tumor irradiation. The application of intelligent and automated technologies is expected to improve treatment process efficiency and precision, supporting doctors in treatment planning and implementation decisions. Globalization and resource sharing will promote the widespread use and optimization of radiotherapy technology worldwide, especially in resource-limited areas, where shared experiences and technologies will play a key role in improving global cancer treatment levels and equity. In summary, future developments in radiotherapy technology will integrate technological innovation, personalized treatment, and global cooperation to provide more effective and accessible treatment options for cancer patients, contributing significantly to medical progress and global health.

6. Conclusions

Radiotherapy, as a crucial cancer treatment method, has made significant progress and achievements over the past decades. This paper delved into the technical

characteristics and clinical applications of various contemporary radiotherapy equipment, detailing the unique roles and advantages of linear accelerators (LINAC), radionuclide therapy machines, and hadron therapy equipment in cancer treatment. By exploring future trends in radiotherapy technology, we anticipate promising developments in personalized treatment, technological innovations, multimodal treatment strategies, biological dose modulation, and the application of intelligent and automated technologies, as well as global cooperation and resource sharing. In conclusion, radiotherapy represents not only an essential cancer treatment method but also a testament to continuous medical technological progress and innovation. With ongoing scientific research and technological advancements, we are confident in the future contributions of radiotherapy to improving treatment outcomes and patient quality of life. We look forward to the further popularization and application of radiotherapy technology globally, bringing more hope and opportunities to cancer patients and making significant contributions to the advancement of health care.

Conflicts of Interest

The author declares that there is no conflict of interest regarding the publication of this article.

Funding

This research received no specific grant from any funding agency in the public, commercial or not-for-profit sectors.

References

- [1] Jin, L.Y. Clinical dosimetry evaluation of IMRT for prostate cancer based on domestic and imported linear accelerators. *China Medical Equipment*, 2021, 36(4), 86-89.
- [2] Ma, N. et al. Development and challenges of precision radiation therapy for tumors. *China Medical Equipment*, 2021, 36(12), 149-153.
- [3] Chen, G.X. et al. Clinical application of intensity modulated radiation therapy based on orthogonal double-layer grating. *Chinese Medical Devices*, 2021, 36(4), 81-85.
- [4] Yang, Bo, et al. "Clinical application of a new" ring "rack accelerator in postoperative pelvic radiotherapy for cervical cancer." *China Medical Equipment*, 2021, 36(4), 24-29.
- [5] Cong, X.H. et al. Clinical dosimetry evaluation of domestic and imported precision radiotherapy devices in primary liver cancer and pancreatic cancer. *China Medical Equipment*, 2021, 36(4), 90-93.
- [6] Du, X.T. et al. Clinical application and breakthrough of 3D printing based on medical imaging technology. *Tissue Engineering Research in China*, 2021, 25(18), 2887.



© 2024 by the author(s); licensee International Technology and Science Publications (ITS), this work for open access publication is under the Creative Commons Attribution International License (CC BY 4.0). (<http://creativecommons.org/licenses/by/4.0/>)