DOI:10.31557/APJCC.2024.9.4.901

PERSPECTIVES

Precision in Delivery: The Critical Role of Daily Imaging in Radiotherapy for Nasopharyngeal Cancer with VMAT Technique

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Abstract

Nasopharyngeal cancer (NPC) presents unique challenges in radiotherapy due to its complex anatomical location and proximity to critical structures. Volumetric Modulated Arc Therapy (VMAT) has emerged as a highly effective technique, offering precise dose distribution to the target volume and spearing of surrounding normal tissues and organ at risks (OARs). The integration of daily imaging in the treatment of NPC with VMAT is pivotal in enhancing treatment accuracy, patient safety and overall clinical outcomes. Daily imaging, utilizing technologies such as cone beam computed tomography (CBCT) and kilovoltage (KV) or megavoltage (MV) imaging plays a crucial role in verifying patient positioning and adapting to anatomical changes. This practice ensures that the radiation is delivered accurately to the target area while minimizing exposure to adjacent healthy tissues and OARs. By facilitating real-time adjustments, daily imaging allows for reduced safety margins around the tumor, thus optimizing the therapeutic ratio. Furthermore, daily imaging contributes to adaptive radiotherapy by monitoring tumor shrinkage and shifts in patient anatomy over the treatment course. This adaptability is essential for maintaining dose precision, particularly in the nasopharyngeal region where minor deviations can significantly impact treatment efficacy and toxicity. Clinical studies have consistently demonstrated that the use of daily imaging in VMAT for NPC leads to improved treatment accuracy, reduced recurrence rates and better preservation of critical structures. The ability to detect and correct for set-up errors and anatomical variations on a daily basis significantly enhances the overall treatment quality. In conclusion, daily imaging is indispensable in the management of nasopharyngeal cancer treated with VMAT. It not only ensures precise delivery of radiation therapy but also enhances patient outcomes by allowing for real-time adjustments and reducing unnecessary radiation exposure. As technological advancements continue, the role of daily imaging in radiotherapy will likely become even more integral, further improving the effectiveness and safety of cancer treatments.

Keywords: Radiotherapy- Nasopharyngeal cancer- Volumetric modulated arc therapy- OAR- CBCT

Asian Pac J Cancer Care, **9 (4)**, 901-904

Submission Date: 07/23/2024 Acceptance Date: 10/28/2024

Introduction

Nasopharyngeal carcinoma (NPC) is a malignant tumor that arises from the epithelial cells of the nasopharynx. Nasopharyngeal carcinoma presents unique challenges in radiotherapy due to its complex anatomical location and proximity to critical structures. Given its unique location, surrounded by critical structures such as the brainstem, spinal cord, optic nerves and contralateral parotid glands, precise targeting of radiation therapy is required or paramount. In the landscape of cancer treatment, advancements in technology have paved the way for more precise and effective radiation therapy techniques. Among these innovations, Volumetric Modulated Arc Therapy (VMAT) stands out as a cornerstone in the management of nasopharyngeal cancer (NPC) [1]. However, to fully

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harness its potential, daily imaging plays a pivotal role in ensuring accuracy and efficacy throughout the treatment course.

Anatomy and Tumor Characteristics of Nasopharyngeal Carcinoma

The nasopharynx is a complex anatomical region located at the back of the nasal cavity, where the nasal passages connect to the throat. Nasopharynx is a cuboidal shape [2]. The nasopharynx extends from the cranial base to soft palate and is continuous with the nasal cavity via the choanae anteriorly (base of sphenoid sinus and cranial base superiorly, nasal cavity and choanae superior-anteriorly, pharyngeal side of soft palate inferior-anteriorly and laterally ostium of eustachian tubes, tubal tonsil) [3].

Nasopharyngeal carcinoma is a type of head and neck cancer that originates in the nasopharynx. NPC is characterized by its unique anatomical location, deep-seated nature, and proximity to critical structures such as the skull base, carotid arteries, and cranial nerves. NPC tumors often present with an infiltrative growth pattern, making it challenging to determine the full extent of the disease. Due to the anatomical complexity of the nasopharynx, NPC can spread in various directions, including into the nasal cavity, paranasal sinuses, parapharyngeal space, and even the intracranial compartment. Understanding the detailed anatomy and tumor characteristics is crucial for effective treatment planning and delivery.

Role of VMAT in Nasopharyngeal Carcinoma

VMAT is an advanced form of intensity-modulated radiotherapy (IMRT), offers a sophisticated solution by delivering highly conformal radiation doses to the tumor while sparing surrounding healthy tissues. Its ability to dynamically adjust the radiation beam's shape, intensity, and dose rate during treatment delivery maximizes precision and efficacy.

VMAT allows for the continuous delivery of radiation dose as the gantry rotates around the patient simultaneously changing dose rate to offer more precise modulation. This technique provides several advantages over traditional radiation therapy, including reduced treatment time and improved dose distribution [4]. In NPC, VMAT's ability to conform to the irregular shape of the tumor and minimize exposure to nearby critical structures is particularly beneficial.

About On-Board imaging

On-Board imaging is a technique in the modern era of radiotherapy, it involves the use of imaging devices such as kilovoltage (KV) source arm and detector panel, mega voltage (MV) detector panel integrated with the modern medical linear accelerator (LINAC) to acquire images and then reconstruct and serialized these images in three-dimensional or two-dimensional form of the patient immediately before each treatment session. These acquired images then compared with the reference images from the treatment planning system and rectify the set-up error, shrinkage of tumor and node etc. Some on-board imaging's are cone beam computed tomography (CBCT), megavoltage computed tomography (MVCT) and two-dimensional planner images using electronic portal imaging device (EPID) (i.e.; KV/KV images, MV/MV images, MV/KV images). Now-a-days MRI based LINAC is also available.

Modern on-board imaging systems are seamlessly integrated with treatment planning software, allowing for automatic comparison and alignment of daily images with reference images from the treatment plan [5, 6]. This integration streamlines the workflow and enhances the accuracy of patient setup.

The Necessity of Daily Imaging: The integration of daily imaging in the treatment of NCP with VMAT is pivotal in enhancing treatment accuracy, patient safety and overall clinical outcomes. Daily imaging also known as Image Guided Radiotherapy (IGRT), involves acquiring images immediately before treatment to ensure precise targeting. Among the imaging modalities cone-beam computed tomography (CBCT) or megavoltage computed tomography (MVCT) prior to each treatment session, can visualize the tumor and surrounding anatomy in real-time, allowing for immediate adjustments to the treatment plan as needed. The most important aspects which increased the importance of daily imaging are-

1. Enhanced Patient Positioning and Setup Verification: By verifying patient positioning before each treatment session, daily imaging minimizes setup errors and enhances treatment accuracy. Through comparison with reference images from the planning stage, clinicians can detect and rectify discrepancies, optimizing patient alignment for precise radiation delivery.

2. Adaptive Radiation Therapy (ART): Daily imaging facilities both online and offline ART, where treatment plans can be adjusted based on changes in tumor size and shape during the treatment course. This adaptability ensures that the dose distribution remains optimal throughout the treatment, improving the chances of tumor control [7-9]. Through daily imaging, clinicians can adapt the treatment plan accordingly, ensuring that the prescribed dose is delivered precisely to the intended target while minimizing collateral damage to adjacent structures.

3. Tumor position variability: The nasopharynx is susceptible to positional changes due to the factors such as patient movement, weight loss and tumor shrinkage during the treatment course [10, 11]. Daily imaging allows for real-time adjustments to the patient's position, ensuring that the radiation is consistently delivered to the intended target.

4. Reduction Of Margin: By verifying the tumor's location daily clinicians can reduce the planning target volume (PTV) margins. Smaller margins decrease the dose to surrounding normal tissues, thereby reducing the risk of radiation-induced toxicity to healthy tissues improving the patient's quality of life [12].

5. Mitigation of Treatment-Related Toxicity: The integration of daily imaging into VMAT protocols reduces the risk of treatment-related toxicity by ensuring that radiation is delivered precisely to the intended target. This minimizes collateral damage to adjacent structures,

thereby enhancing patient safety and quality of life during and after treatment.

6. Personalized Treatment Strategies: Daily imaging facilitates a personalized approach to NPC treatment by accounting for individual variations in tumor response and anatomy. Continuous monitoring throughout the treatment course enables clinicians to tailor interventions based on patient-specific parameters, maximizing therapeutic outcomes and minimizing toxicity.

7. Improved Accuracy and Outcomes: Studies have shown that daily imaging improves the accuracy of radiation delivery, leading to better local control of tumor and potentially higher survival rates. Accurate targeting minimizes the likelihood of geographical misses, where parts of the tumor might receive suboptimal doses, which could compromise treatment efficacy.

Technical Advancements in Daily Imaging

Advancements in imaging technology have significantly enhanced the quality and efficiency of daily imaging. CBCT for instance provides three-dimensional images that allow for precise assessment of tumor tissue positions. These advancements not only improve the accuracy of patient positioning but also reduce the time required for image acquisition and analysis, making daily imaging more feasible in a busy clinical setting.

Challenges and Considerations

While daily imaging offers numerous benefits but also presents challenges. These are:

1. Increased Radiation Exposure: Daily imaging adds to the cumulative radiation dose received by the patient. However, the benefits of improved targeting often outweigh the risks associated with this additional exposure.

2. Recourses and Time Intensive: Implementing daily imaging requires additional resources, including specialized equipment and trained personnel. It also extends the time patients spend in the treatment room, which can impact clinical workflow.

3. Patient Compliance: Ensuring that patients remain still during imaging and treatment is crucial after wearing thermoplastic cast. Patient comfort and co-operation are essential for the success of daily imaging protocols.

Future Directions

As technology continues to advance, the role of daily imaging in NPC management with VMAT technique is poised to evolve further. Emerging modalities and strategies aimed at enhancing imaging quality and efficiency hold promise for further optimizing treatment outcomes and expanding the scope of personalized cancer care.

In conclusion, yet the success of VMAT in NPC treatment hinges on accurate target localization and patient positioning, factors susceptible to variation due to anatomical changes, organ motion, and setup uncertainties. This is where daily imaging assumes paramount importance. In the era of precision medicine, the importance of daily imaging in NPC treatment with VMAT technique cannot be overstated. By providing real-time visualization and enabling adaptive treatment strategies, daily imaging enhances precision, safety and efficacy ultimately improving outcomes and quality of life for patients battling this challenging disease. As we continue to refine our approach to cancer care, embracing technologies that offer such precision and adaptability will undoubtedly pave the way for improved outcomes and enhanced quality of life for patients battling this challenging disease. Daily imaging is indispensable in the management of nasopharyngeal cancer treated with VMAT.

Acknowledgments

Compliance with Ethical Standards

Financial disclosure

There is no specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Ethical approval

NA

Conflicts of Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper

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