Chelonian Conservation And Biology

Vol. 17No.2 (2022) | https://www.acgpublishing.com/ | ISSN - 1071-8443

DOI:doi.org/10.18011/2022.04(1) 1479.1487

IMPACT OF RADIOLOGY PROTOCOLS ON RADIATION DOSE REDUCTION

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Abstract

Image-guided radiation treatment (IGRT) has revolutionized radiotherapy by using imaging technologies for precise patient placement and target localization. The administration of the imaging dose may lead to an excessive amount of radiation being received by sensitive organs, which might possibly raise the risk of developing secondary malignancies. As a consequence, it is crucial to effectively control and regulate the dosage. We provide a concise overview of the radiation dosage received by patients undergoing radiotherapy (RT) as a consequence of various image guiding processes. Additionally, we provide a compilation of the average doses received by organs during the capture of MV and kV images. While the imaging dosage from modern kV acquisition technologies is often below this level, it is important to constantly use the ALARA principle in practice. Medical physicists should inform radiation oncologists about the imaging doses given to patients under their supervision. In order to effectively locate the target, it is necessary to balance the ALARA principle (As Low As Reasonably Achievable) with the need for accurate target localization. This involves managing the imaging dosage by carefully assessing and evaluating the risks and benefits to the patient.

Keywords: Radiology, scan imaging, dose calculation, image-guided radiation treatment (IGRT).

1. Introduction

Image-guided radiation therapy (IGRT) has quickly become the accepted standard for enhancing the precision of patient placement during radiotherapy. 1-6 Image-Guided Radiation Therapy (IGRT) may effectively decrease mistakes in target location, therefore facilitating precise and accurate treatments. The obtained pictures during the administration of therapy may be used for the purpose of monitoring changes in the patient and target geometry, possibly adaptive planning,7-9 or reduction of margins.10 Throughout the duration of IGRT, the image guidance method is usually carried out for every treatment fraction. Occasionally, the patient may have several imaging procedures during a single treatment session to verify the accuracy of their posture and make adjustments if needed. Given that these imaging technologies expose patients to extra radiation, it is crucial to comprehend the extent of this radiation dosage in order to mitigate potential risks.

Although the well accepted radiation protection safety principle of As Low As Reasonably Achievable (ALARA) applies to imaging dosage, it is important to ensure that efforts to minimize imaging doses do not impair target localization. At now, the dose of radiation used for imaging is not taken into consideration during radiation therapy treatment planning. The objective of this study is to provide data on the dosage of radiation used for imaging and establish recommendations for doctors to make well-informed judgments about the potential risks and advantages of using x-ray image guiding.

The AAPM TG-751 study included dose estimates for several image guiding modalities and proposed ways for reducing imaging radiation while enhancing treatment administration. TG-75 also recognized the need of effectively controlling the amount of radiation exposure from various imaging methods used in radiation therapy, both existing and upcoming. The methods included in this list are CT (computed tomography), 4D-CT (four-dimensional computed tomography), diagnostic x-ray imaging, in-room CT, dual radiographic x-ray imaging, fluoroscopy, and portal imaging, which may be done using either film or an electronic portal imaging device (EPID) in different modes.

This study is designed to supplement the AAPM TG-75 report.1 The data provided is up-to-date and includes the latest information on dosage obtained via contemporary imaging techniques. It also covers the current challenges in accurately predicting and accounting for the radiation dose during treatment planning, as necessary. Additionally, it discusses methods for reducing radiation exposure during medical imaging operations and offers guidance on implementing the guidelines outlined in AAPM TG-751 and ICRP-102.12. This paper also provides instructions for commissioning imaging beams to provide patient-specific imaging dosage estimations, when required.

The imaging dose mentioned in this report refers to the absorbed dosage to a specific medium, such as bone or soft tissue. This is distinct from the effective dose metric used in TG-75. The effective dose, as defined by the International Commission on Radiological Protection (ICRP), is calculated by considering the overall biological impact of radiation on the whole body of the patient. This calculation requires a thorough understanding of the energy distribution of the radiation and the way it is distributed throughout the body. The majority of treatment planning systems (TPSs) lack the ability to calculate and provide dose distributions within the kV energy range, unless equipped with specific research tools. Additionally, most systems are unable to transform computed absorbed dosage into effective dose and show the outcomes. Therefore, to circumvent this added layer of intricacy, this study use absorbed dosage instead of effective dose.

The quantity of the imaging dosage is contingent upon several elements, such as the frequency of imaging and the used technology. During a single treatment session, it is possible to get two or more flat pictures or one or more three-dimensional scans. For Brainlab AG's ExacTrac14, 15 or Accuray, Inc.'s CyberKnife systems, the number of planar image acquisitions per session can exceed 80. This is common even for treatments that are not SRS/SBRT, as frequent imaging is necessary to monitor the patient's position. Each of these imaging methods exposes normal tissue to an extra dosage of radiation.18-25 The imaging dosage administered to the patient might vary significantly depending on the specific imaging procedures and methods used.

Typically, MV imaging administers greater doses compared to kV imaging.26-28 Except for MV volumetric imaging, a single picture capture may provide a radiation dosage of 0.1–5.0 cGy to the patient, depending on the imaging modality. Despite the success shown in reducing the dosage, the kV-CBCT technique used for pelvic imaging might still contribute a cumulative dose of 1-3% of the prescribed dose during the treatment period. Due to the photoelectric effect being the primary pathway for photon interaction in kV imaging, the dosage of radiation absorbed by bony structures is 2-4 times higher than that absorbed by soft tissue.29 During an MV-CBCT image capture, the amount of radiation exposure may exceed 10 cGy, varying depending on the specific location being imaged and the clinical procedure being followed.23 During imaging treatments, the volume being scanned is often bigger than the volume being treated. As a result, tissues and organs beyond the area being treated are exposed to radiation from the imaging process. It is important to effectively handle the imaging dosages that affect organs beyond the treatment area, since they might provide a higher risk, particularly for young patients.

This article provides an overview of many techniques used to quantify the amount of radiation exposure in x-ray imaging. The methods used to determine the dosage of kV-CBCT imaging include experimental phantom measurements, in vivo measurements on patients, and Monte Carlo computations.21, 22, 25, 26, 27, 29 Treatment planning systems that are available for purchase, together with user customizations and mathematical models, have been used to compute the dosage for MV-CBCT and kV-CBCT. Measurements have been used to approximate doses from 2D kilovolt (kV) radiography, kV-cone beam computed tomography (CBCT), megavolt (MV) portal images, MV-CBCT, and MVCT. 30, 31

In the field of radiation treatment, the recommended therapeutic dose refers to the lowest amount of radiation that is given to a specific area or the whole intended target volume. When formulating plans for controlling the imaging dosage, this work group deems it necessary to take into consideration the imaging dose in the treatment planning process after it exceeds 5% of the therapeutic target dose. According to Dische et al.32, published clinical data and an analysis of the Continuous Hyperfractionated, Accelerated Radiotherapy (CHART) pilot study data 33 provide evidence that even small dose variations of 5% can result in actual variations in both tumor response and the risk of morbidity.34 Several research studies on accuracy requirements in radiotherapy have suggested a required accuracy level of ±5% for the administration and calculation of radiation dosage to both malignancies and normal tissue. 35 Therefore, the selection of a 5% threshold is determined by factors such as the importance in clinical settings, precision in calculating and administering doses, acceptable levels of radiation for vital organs, and practicality in real-world medical practice. The existing research, which has been referenced in this article, suggests that the imaging dosage for patient groups receiving IGRT is often below 5% of the therapeutic goal dose, with the exception of some imaging techniques that use MV beams, including MV-CBCT.36 To effectively localize the target while adhering to ALARA principles, it is necessary to carefully limit the imaging dosage by evaluating and balancing the risks and benefits to the patient.

2. Summary of the dosage obtained from image guiding processes

Megavoltage beam imaging refers to the use of high-energy beams, typically in the megavoltage range, for the purpose of imaging. Megavoltage imaging techniques use either electronic portal imaging devices (EPIDs) or a single-row CT detector in the case of MVCT in the Tomotherapy Hi-Art Radixact system (Accuray Inc., Sunnyvale, CA) to collect projection pictures. The acquisition of a pair of orthogonal 6 MV portal pictures with an EPID often produces a dose distribution similar to the one seen in Figure 1(b). The organ doses range from 1 to 5 cGy. Additionally, the imaging dosage from a 2.5-MV image beam is about 50% of the dose obtained from a 6-MV beam.37

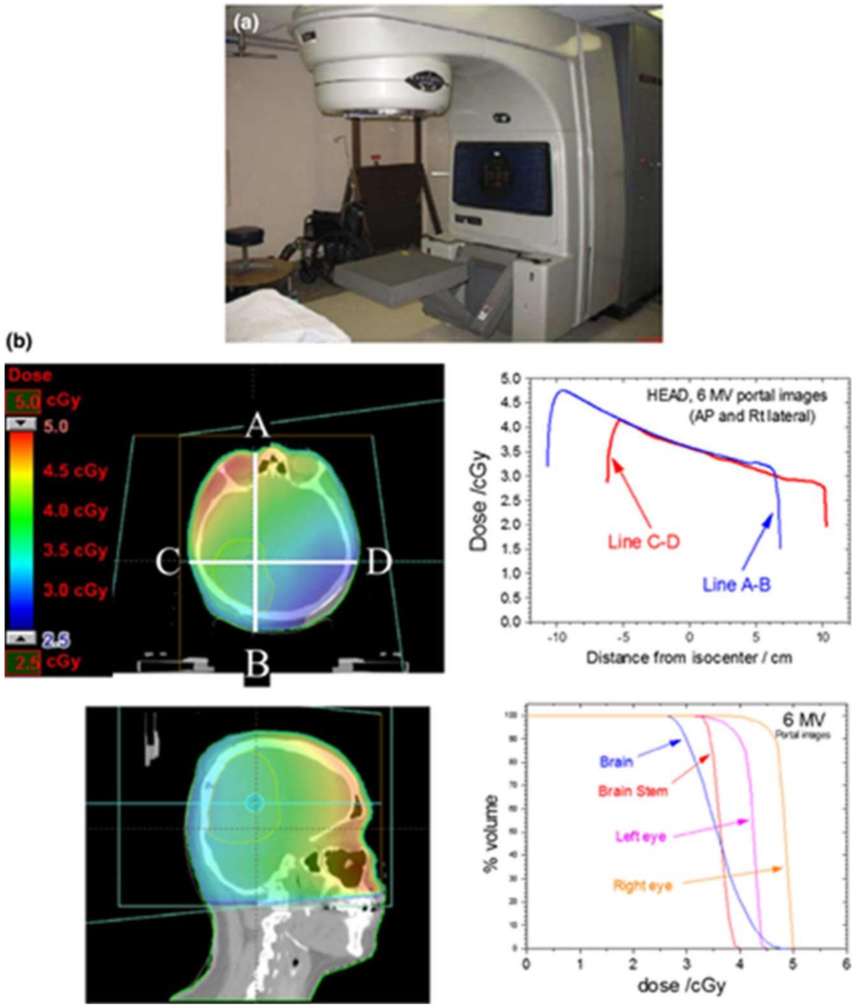

Figure 1. A conventional electronic portal imaging device (EPID) and the resultant dose distributions and organ dose-volume histograms (DVHs) from a pair of orthogonal 6 MV portal pictures (2 MU per image). 26

Radiation calculation methods for kilovolt (kV) and megavolt (MV) imaging radiation have seen major advancements in the last thirty years, establishing Monte Carlo (MC) approaches as the most accurate and reliable method for dose estimations. They have been used to replicate high-energy and low-energy beams, enabling precise computations of the distribution of radiation dosage in patients caused by various x-ray imaging methods. However, none of the present methods provide Monte Carlo simulations for kilovolt (kV) beams.

Accurate estimations of MV beam dosage are achieved via the use of model-based methodologies, which are widely integrated into commercial treatment planning systems. These techniques can precisely compute the imaging dosage in cases when an imaging process employs MV beams. Nevertheless, when used for kV beams, these methods exhibit intrinsic errors, leading to an underestimation of bone dosage by as much as 300%.

The Medium-Dependent Correction (MDC) technique is a suggested method that considers the reliance on atomic number while calculating kV dose distributions. This method has the potential to enhance the accuracy of kV imaging dose estimations by 10-20%. With further advancements in commercial treatment planning systems (TPSs), it may become practical to use the same model-based algorithms for calculating doses from both a therapeutic beam with megavoltage (MV) and an imaging beam with kilovoltage (kV).1,11,15,18,19

3. Techniques for calculating and accounting for imaging dose

Imaging dose estimates are used to quantify the dosage of radiation treatment (RT) administered to patients. When the dose surpasses 5% of the recommended dosage, there are two approaches that may be employed: patient-specific dose computations and nonpatient-specific dose estimations. Customized dose estimations for each patient are derived from CT scans and provide personalized organ dosages. Treatment planning systems are uncomplicated when the beams used for imaging procedures are identical to the therapeutic beam. The overall quantity of imaging procedures may be accounted for throughout the process of treatment planning. Nonpatient-specific dose calculations may be performed using simple look-up tables, which can provide precise estimates of the exposure from repeated imaging operations. The tabulated data may assist doctors in assessing if the doses are likely to approach the 5% threshold, selecting an appropriate IGRT protocol, and considering the organ dosage arising from a particular image capture operation during the treatment process.21,25

4. Conclusion

Unlike diagnostic imaging techniques, IGRT picture acquisitions are performed more often, on a daily basis, and include a broader volume than the area being treated. Effective administration of imaging dosage in IGRT involves following ALARA principles, which include limiting the dose to the greatest extent feasible and considering it when required.

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