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An overview of radiation therapy dosimetry

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1. Introduction

Radiotherapy is a truly interdisciplinary area encompassing physical, mathematical, computational, and biological knowledge, which undergoes constant advances due to the progress of knowledge in these different areas. As a result, the current level of technological development is very high, with the possibility of delivering very high doses of radiation in very well-defined volumes, which requires high precision when carrying out these procedures.

The evolution of radiation therapy treatments has been marked by a focus on precision and accuracy [1]. It began with the introduction of conformal radiotherapy (3D), which used computerized three-dimensional planning and progressed to intensity-modulated radiotherapy (IMRT). IMRT, with its beam intensity variation in each target region, allows for the irradiation of complex volumes near critical structures [2]. Volumetric Modulated Arc Therapy (VMAT) appeared as the next evolution in dose delivery. It is a new type of IMRT in which the linear accelerator rotates around the patient during treatment. The machine continuously reshapes and changes the intensity of the radiation beam as it moves around the body [3]. This level of precision has led to the highest-ever achieved dose conformance to the treatment target.

At the same time, we can describe developments in the delimitation of tumors and also in monitoring the patient's positioning throughout treatment. The morphology and positioning of tumors can currently be defined with great accuracy through the fusion of medical images, mainly from magnetic resonance imaging (MRI) or positron emission tomography (PET) to computed tomography (CT) images, usually used for planning radiotherapy treatments. Furthermore, the emergence of Image Guided Radiation Therapy (IGRT) using 2D and 3D imaging modalities in the radiotherapy process aims to detect deformation and movements of the target volume between treatment fractions or even during treatment application to correct them. These innovations allow the reduction of the margins associated with the target volume due to uncertainties in tumor location and also variations in positioning throughout treatment delivery [4]. All of this, associated with IMRT dose delivery, allows a higher radiation dose to be delivered in treatments and makes it possible to carry out hypo-fractionated stereotactic radiotherapy (SRT) or stereotactic body radiotherapy (SBRT) treatments [5].

When optimally used, all this technology (IMRT, IGRT, SRT/SBRT...) can potentially improve the efficiency of radiotherapy treatments and increase the cure rates of patients undergoing this treatment. However, for professionals involved in the clinic, it is a great challenge to introduce and apply these technologies in a precise and safe manner. For this reason, great emphasis is given to quality control systems to explore the benefits of this technology, achieving the cure of patients and not resulting in accidents due to the misuse of these advances.

In this context, the present study aims to review the main dosimetric systems available for radiotherapy and describe their clinical application.

2. Methodology

A literature review of the main documents and guidelines for radiotherapy quality control was conducted, and the recommended dosimeters for several different procedures were identified and presented.

3. Results and Discussion

As described before, radiotherapy evolution occurred in the sense of conforming the doses to the target volumes. Ideally, the dosimetric systems able to verify these dose deliveries must follow this tendency, which represents an increasing need for volumetric dose detectors. So, in this area, we have a balance between very accurate and precise point dose detectors and 2D or 3D dosimeters.

There are established tasks for point dose measurements, such as reference dosimetry performed with calibrated ionization chambers [6]. In vivo dosimetry of the simplest technologies is another usual task for point detectors, and here we can cite the use of thermoluminescent dosimeters (TLD) and optically stimulated luminescence (OSL) dosimeters, among others [7].

Following the introduction of IMRT, the use of 2D detectors became necessary because there was a clinical need for improved tools for commissioning, pretreatment measurements, and in vivo quality assurance methods. These tasks were initially done using film dosimeters, mainly with radiochromic films [8], but the emergence of array detector systems has revolutionized dosimetry for applications such as IMRT pretreatment QA measurements with real-time response. However, considering the high conformal doses delivered by these techniques, the need for 3D detectors became evident once they were the only ones capable of verifying all the doses delivered by the treatments [9]. The semi-3D detectors were the first employed in the clinical setting for this aim. These include detector arrays that make measurements in two or more plans or also in a cylindrical geometry, and then a 3D "measured" dose cube is interpolated from the measured data. However, it is important to highlight that the final data available is interpolated and not completely measured. Full 3D dose measurements are only possible with special dosimeters such as GELS, scintillators, or Cherenkov detectors, with the gels being the most promising and studied ones. Scintillators are not tissue equivalent, and Cherenkov detectors still need further extensive studies before clinical applications.

4. Conclusions

An overview of the present technology in radiotherapy was presented, as well as the associated radiation detector used for its dosimetry and quality control. It is possible to verify the need for an evolution of the dosimetric techniques to provide the safe implementation of radiation treatments.

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