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EDITORIAL

Real-time dosimetry in external beam radiation therapy

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Abstract

With growing complexity in radiotherapy treatment delivery, it has become mandatory to check each and every treatment plan before implementing clinically. This process is currently administered by an independent secondary check of all treatment parameters and as a pre-treatment quality assurance (QA) check for intensity modulated radiation therapy (IMRT) and volumetric modulated arc therapy treatment plans. Although pre-treatment IMRT QA is aimed to ensure the correct dose is delivered to the patient, it does not necessarily predict the clinically relevant patient dose errors. During radiotherapy, treatment uncertainties can affect tumor control and may increase complications to surrounding normal tissues. To combat this, image guided radiotherapy is employed to help ensure the plan conditions are mimicked on the treatment machine. However, it does not provide information on actual delivered dose to the tumor volume. Knowledge of actual dose delivered during treatment aid in confirming the prescribed dose and also to replan/reassess the treatment in situations where the planned dose is not delivered as expected by the treating physician. Major accidents in radiotherapy would have been averted if real time dosimetry is incorporated as part of the routine radiotherapy procedure. Of late real-time dosimetry is becoming popular with complex treatments in radiotherapy. Real-time dosimetry can be either in the form of point doses or planar doses or projected on to a 3D image dataset to obtain volumetric dose. They either provide entrance dose or exit dose or dose inside the natural cavities of a patient. In external beam radiotherapy, there are four different established platforms whereby the delivered dose information can be obtained: (1) Collimator; (2) Patient; (3) Couch; and (4) Electronic Portal Imaging Device. Current real-time dosimetric techniques available in radiotherapy have their own advantages and disadvantages and a combination of one or more of these methods provide vital information about the actual dose delivered to radiotherapy patients.

Key words: Cancer; Radiotherapy; External beam; Dosimetry; Real-time

Core tip: Treatment outcome in radiotherapy is highly dependent on the dose delivered to the tumor volume with minimal dose to the surrounding critical structures. Real-time dosimetry plays a crucial role in assessing the accuracy of dose delivered to patients undergoing radiotherapy. Several radiotherapy accidents would have been avoided if real-time dosimetry was part of the radiotherapy treatment procedure. This article highlights different approaches to assess real-time dosimetry in external beam radiotherapy.

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INTRODUCTION

Radiotherapy plays a vital role in the treatment of cancer. Advances in external beam radiotherapy, such as three-dimensional conformal radiotherapy and intensity modulated radiation therapy (IMRT), tightly conforms dose to the target volume, in turn reducing dose to the surrounding critical structures. Highly conformal dose distribution in the presence of critical structures is possible with IMRT due to its capability of achieving a very rapid dose fall-off. Clinical studies have demonstrated that conformal and high dose radiation treatments equate to an increase in the tumour control probability with reduced normal tissue complication probability[1-3]. This can only be achieved if the dose is delivered precisely to the target volume. Whilst there are a number of factors that affect precision in delivered dose, usually the most important factor is misalignment of the patient. Any misalignment or wrong patient setup during high dose radiotherapy may have serious consequences on the treatment outcome. Thus, it is increasingly important to position the patient precisely and to regulate or monitor the position of the internal organs. Image guided radiotherapy aids in precisely positioning the patient to the treatment isocentre. The local control, morbidity and survival rates of radiotherapy patients depend on the accuracy of radiation dose delivered to the tumor volume and avoidance of dose to peripheral normal tissue. Knowledge of the actual dose delivered is critical to our understanding of the physical parameters that determine the radiation response of a tumor. This knowledge will assist in optimizing the dose delivered to the tumor volume on an individual patient basis. Verification of the actual treatment delivery can prevent errors that may entail severe consequences to the patient and achieve the efficacy of treatment. Several radiotherapy incidents have led to serious injury or death such as in Panama[4], Exeter (United Kingdom)[5] and Costa Rica[6]. Moreover, it is reasonable to suggest that recent accidents in Epinal (France)[7] and Glasgow (United Kingdom)[8] could have been avoided if the delivered dose had been verified during treatment. Several international agencies such as IAEA, ICRP, WHO and professional societies of radiation oncology such as AAPM, ESTRO, NACP *etc.*, recommend the use of *in vivo* dosimetry as a possible solution to avoid radiotherapy accidents.

It has become mandatory to check each and every component of a treatment plan before implementing clinically. This process is currently administered as secondary check and as a pre-treatment quality assurance (QA) with IMRT and volumetric modulated arc therapy treatment plans. Although pre-treatment IMRT QA is aimed to ensure the correct dose is delivered to the patient, it does not necessarily predict the clinically relevant patient dose errors during treatment as the measurement is usually performed on a water equivalent phantom[9]. During radiotherapy, treatment uncertainties arise from setup error, tumor deformation or shrinkage, and organ motion that ultimately lead to dose variation. This variation affects tumor control and the chance of increased normal tissue complications. To combat this, image guided radiotherapy helps ensure the plan conditions are mimicked on the treatment machine. However, it does not provide information regarding whether the plan dose is delivered to the tumor correctly. There are several means of evaluating the dose delivered, but currently there is no system developed to allow for rapid real-time assessment. Within the linear accelerator there are four established platforms whereby the delivered dose information can be obtained: (1) Collimator; (2) Patient; (3) Couch; and (4) Electronic Portal Imaging Device (EPID).

At the collimator level, dose information could be obtained by two methods. The first method involves ascertaining the leaf positions and/or field defining apertures during treatment delivery. The dose information could be obtained with simple dose calculation by simulating the position of these leaves and or apertures onto the planning computed tomography (CT) or cone beam computed tomography (CBCT) scans. Alternatively, the relevant dose information could be achieved by the application of external attachments to the collimator. Such external attachments may include a multi-wire transmission ionization chamber[10] or a 2D-array of detectors[11] attached to the collimator. These methods rely on the patient CT data for 3D dose calculation and require either pre or post treatment CBCT to estimate the real-time dose delivered to the patient. The measured dose at the collimator level is projected onto the image datasets to obtain the 3D dose distribution. The most commonly employed methodology in radiotherapy to estimate the dose during radiotherapy is at the patient level and often called as *in-vivo* dosimetry. It is performed by directly placing the detectors on the patient surface or inside the natural cavities of a patient during treatment. There are a number of detectors (dosimeters) commonly used for determining the dose that includes thermoluminescence detectors[12], diodes[13], MOSFETs[14], diamond detectors[15], films[16], optical stimulated luminescence detectors[17], scintillation detectors[18,19] and radio photoluminescence detectors[20] *etc.* In most cases, the measured dose from these dosimeters is usually assessed at one or more points on the patient skin surface or inside the natural body cavities. The main aim of *in-vivo* dosimetry is to detect large errors and prevent potential misadministration. Usually an action level of ± 5% is used for simple treatments and ±7% for complex treatments. *In-vivo* dosimetry acts a potential tool for detecting systematic errors that may escape data transfer/MU calculation checks[21]. The *in-vivo* dosimeters are usually used for estimating the dose to organs at risk and in certain cases to verify the dose to the target volume. It is routinely used for most of the time to ensure that the dose to critical structure does not exceed its tolerance dose. The measured critical structure dose can also be used to correlate with toxicity. *In-vivo* dosimetry is also widely used to assess the out-of-field doses (gonads, spinal cord, lens *etc.*,) during radiotherapy which may predict complications/associated risk of second cancers with high energy photon beam[22,23].

Recently, a couch-based real time dosimetry system has been proposed that can be used for verifying the dose delivered to the patient by embedding a 2D array of detectors in the treatment couch[24]. It provides either exit or entrance dose depending on the gantry or couch position and it is a viable tool for performing daily quality assurance in radiotherapy. This device has the potential of measuring the doses for non-coplanar beam but has limitations in measuring the dose at lateral cardinal angles. Another device that can be used to obtain dose information is an EPID, which was originally designed to verify patient positioning and is currently used for quality assurance and transit dosimetry (such as in the pre-treatment verification of IMRT)[25]. In the instance of transit dosimetry, the EPID creates a fluence map and converts this to dose via calibration of the EPID image using an appropriate algorithm. The energy fluence maps acquired from these devices are back projected and deposited to a volumetric dataset (CT/CBCT) captured either during treatment or initial planning CT. The delivered dose is reconstructed from the deposited energy fluence in each voxel of the volumetric dataset after correcting for attenuation coefficients. One of the important drawbacks of EPIDs is the practical difficulty in measuring the dose to most of the non-coplanar beams due to physical limitations as the imager would collide with the treatment couch. This disadvantage could be overcome by combining a couch-based dosimetry system with EPID for real-time dosimetry. With existing technology, 3D *in-vivo* dosimetry can be achieved with collimator based/EPID based methodology. In clinical situations, 3D *in-vivo* dosimetry helps in assuring the prescribed dose is delivered as expected by the treating physician and also for adaptive radiotherapy. Especially for tumors that are prone to movement during treatment, 4D real-time dosimetry is currently being investigated as a possible solution[26,27,28]. With evolving technology, the implementation of real-time dosimetry routinely is becoming a reality and this may avert major accidents in radiotherapy. Current real-time dosimetric techniques available in radiotherapy have their own advantages and disadvantages and a combination of one or more of these methods may provide vital information about the dose delivered to radiotherapy patients. Real time dosimetry in conjunction with image guidance will be the perfect combination in moving forward towards high-precision radiotherapy.

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