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Future directions of in vivo dosimetry for external beam radiotherapy and brachytherapy

1. Introduction

Radiation therapy is a highly complex process involving teams from different disciplines. Prompted by this complexity and subsequent potential risk of treatment errors, radiation oncology has been a pioneer in the implementation of incident learning systems and prospective risk management in medicine. These efforts have made radiotherapy a safe medical discipline. However, despite the low risk of severe incidents, several registries have documented errors happening in radiotherapy. These errors range from near-misses to severe over and under dosages (for a recent overview, see [1]) and include also an unknown number of undetected errors, the false negatives.

For external beam radiotherapy (EBRT) many radiotherapy institutes participate in dosimetry audits to verify independently their local practice. One study from the Imaging and Radiation Oncology Core Houston Quality Assurance Center (IROC-H) recently reported [2] the results of an IMRT dosimetry audit for a head&neck phantom with thermoluminescent detectors (TLD) and film gamma analysis. They showed that 10% of participating institutes with a wide range of operational size failed to meet criteria of better than ±7% dose agreement with TLD or ≥85% of pixels satisfying a (7%, 4 mm) dose difference/distance to agreement criterion with film. One could assume that it is mostly complex plans that fail, but conflicting reports exist on this in the literature [3,4]. There may be some evidence that plans consisting of many small field segments may lead to larger uncertainties [5]. The IROC study mentioned may be an extreme case, since especially in Europe usually higher compliance rates are reported (see [6] and references therein). The large reported differences in compliance rates may reflect differences in codes of practice, complexity of the audits, postal or onsite audits, detectors used etc. Although highly recommended, audits can also not guarantee treatment quality on other days. Furthermore, for brachytherapy (BT) less auditing and less verification, in particular during therapy, is performed than for EBRT.

The emphasis of verifying the radiotherapy treatment chain is currently mainly on equipment and dosimetry checks which are performed pre-treatment. However, these checks cannot catch a variety of errors occurring during delivery of the actual treatment e.g. related to patient geometry or to applicators for brachytherapy. Therefore, a substantial need exists for systems that can constantly monitor deviations in the treatment dose that may be relevant to the outcome of the treatment. The most direct way to assess the treatment dose is through in vivo dosimetry (IVD). After the first ESTRO Physics Workshop, held in Glasgow in November 2017, it was decided to start a Task Group on IVD, with the aim of providing reports on the use of IVD for both EBRT and BT. This editorial gives an overview of the requirements identified by the Task Group, while more details for the individual modalities can be found in the respective reports published in this and the previous volume [7,8].

2. Scope

The EBRT and High Dose Rate (HDR) BT reports [7,8] followed a unified IVD approach. Much attention was given to electronic portal imaging detector (EPID) panels for EBRT and on time resolved dosimetry for brachytherapy. The purpose of the reports was to identify the key reasons for low adoption of IVD in the clinic and to specify the requirements needed for advancing the field to a significantly higher adoption in clinical practice.

The current Task Group did not focus on Low Dose Rate BT and EBRT methods such as electron beams, Tomotherapy, CyberKnife, Halcyon, kilovolt photon beams, ion beams and MR-linac.

3. Definition

Before embarking on this mission, it was important to formulate a general consensus definition of IVD, which was then used in the two ensuing reports (for BT and EBRT).

IVD is a radiation measurement that is acquired while the patient is being treated, containing information related to the absorbed dose in the patient. This definition implies that an IVD system must be able to capture errors due to equipment failure, errors in dose calculation, patient/applicator positioning errors, and patient anatomy changes.

In this definition, “Patient positioning error” refers to EBRT and “applicator positioning error” to BT.

More details on which methods are included and excluded from this definition and further specific refinements for IVD for EBRT and BT are given in the two reports [7,8]. These also state which developments are needed to turn some methods into true IVD.

4. Aims

An IVD method should satisfy at least one, but preferably all four, of the following aims:

1. To provide a safety system to catch planning or treatment errors that can significantly affect the patient
2. To provide tools for treatment adaptation, i.e. to correct a fractionated therapy, either during the treatment or before the next fraction
3. To record the true dose received by the patient compared to the planned dose

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4. Be practicable and comfortable for the patient.

Ideally, an IVD system should record a signal in real time that can be converted to a dose without perturbing the patient dose itself. The 'real time' aspect is important to catch (gross) treatment errors before they can affect the patient e.g. in hypofractionated EBRT or BT. Modern information analysis methods such as artificial intelligence based systems to detect errors and their possible causes may also play a role in the further development of IVD.

5. Requirements

The conclusions of the EBRT and BT IVD reports can be summarized by a number of requirements. IVD is an ideal technique to check independently that all radiotherapy fractions, and all parts of it are correctly administered. However, the full benefit of any approach is only reached if the techniques: 1) are commercially available, 2) are straightforward to implement in clinical practice, 3) require minimal and easy to perform QA procedures, 4) are accurate enough to detect relevant errors with acceptable false positive and false negative rates, 5) have acceptable requirements for resources and manpower, 6) are preferably fully automated, and 7) are fully integrated in the patient workflow.

For current IVD systems, there are in general issues with one or more of these requirements. This has so far impacted the clinical adoption of IVD leading to a general under-utilisation. IVD is currently facing problems both on the sides of clinics and device manufacturers of commercial technology: many clinics do not perform IVD because the clinical benefit is considered too low or because the workflows for usage and/or QA are too demanding with regard to complexity and need for resources. Secondly, although there are quite a few manufacturers in the field, their willingness to invest in IVD is affected by the limited demand from clinics as well as the lack of recommendations and regulations. Thirdly, there is a lack of clinical guidance on the tolerance and action levels, and on how to perform sensitivity and specificity assessments. However, new techniques for IVD are being continuously developed and when combined with automated analysis tools and potential automated treatment interrupt capabilities, IVD has significant potential to facilitate wide clinical use to benefit patient safety.

6. Need for further development

The Task Group identified the available technologies and raised awareness to both users and manufacturers for further required developments in both hardware and software. In general, more research is needed to explore fully the capabilities and limitations of IVD methods for various treatment modalities. The following aspects were identified for further development:

- The sensitivity and specificity of IVD systems, to ensure that systems can identify clinically relevant errors while balancing the amount of false alarms
- The workload and resources needed for clinical implementation, maintenance, QA and daily operation
- The (automatic) data processing and the comparison between predicted and measured signal from IVD systems
- The degree of automation of the systems
- The possibility to derive optimal clinical decision criteria for customized error detection
- The technical specification of the system which is provided by IVD vendors to the users
- The integration of IVD systems with current non-IVD methods.

The authors hope that clinical users and device vendors may find inspiration in these reports to accelerate the clinical introduction of IVD methods.

Declaration of Competing 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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