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A user-oriented procedure for the commissioning and quality assurance testing of treatment planning system dosimetry in high-dose-rate brachytherapy

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ABSTRACT

PURPOSE: To develop a user-oriented procedure for testing treatment planning system (TPS) dosimetry in high-dose-rate brachytherapy, with particular focus to TPSs using model-based dose calculation algorithms (MBDCAs).

METHODS AND MATERIALS: Identical plans were prepared for three computational models using two commercially available systems and the same ^{192}Ir source. Reference dose distributions were obtained for each plan using the MCNP v.6.1 Monte Carlo (MC) simulation code with input files prepared via automatic parsing of plan information using a custom software tool. The same tool was used for the comparison of reference dose distributions with corresponding MBDCA exports.

RESULTS: The single source test case yielded differences due to the MBDCA spatial discretization settings. These affect points at relatively increased distance from the source, and they are abated in test cases with multiple source dwells. Differences beyond MC Type A uncertainty were also observed very close to the source(s), close to the test geometry boundaries, and within heterogeneities. Both MBDCAs studied were found equivalent to MC within 5 cm from the target volume for a clinical breast brachytherapy test case. These are in agreement with previous findings of MBDCA benchmarking in the literature.

CONCLUSIONS: The data and the tools presented in this work, that are freely available via the web, can serve as a benchmark for advanced clinical users developing their own tests, a complete commissioning procedure for new adopters of currently available TPSs using MBDCAs, a quality assurance testing tool for future updates of already installed TPSs, or as an admission prerequisite in multicentric clinical trials.

Keywords: Brachytherapy; HDR; MBDCA; QA; Commissioning; Monte Carlo; BrachyGuide

Introduction

Dosimetric uncertainty of brachytherapy applications can be broadly categorized as consisting of contributions from source strength calibration, dose calculation, and dose delivery that have been reviewed in recent joint societal reports (1, 2). DeWerd *et al.* (2011) focused on the first two uncertainty contributions and discussed dose calculation uncertainty for treatment planning system (TPS) based on the dosimetry formalism outlined in the American Association of Physicists in Medicine task group (TG)-43 report (3). This is calculation point, source, and TPS specific. It includes uncertainty from the consensus dosimetric data set for a particular source (4) which links back to dosimetry investigations in the peer-reviewed literature, and additional uncertainties introduced by the TPS algorithms. In their analysis of clinical brachytherapy uncertainties, Kirisits *et al.* (2014) also reviewed the literature on the Type B (i.e., nonstatistical in nature) dose calculation uncertainties introduced from the principles and assumptions of the TG-43 formalism that do not account for the

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radiological differences of tissues or applicators from water and the patient/implant-specific scatter conditions.

In an effort to reduce these Type B uncertainties and improve dosimetric accuracy of high-dose-rate (HDR) brachytherapy applications using ^{192}Ir sources, advanced dose calculation algorithms have been introduced in commercially available TPSs (5). These algorithms calculate dose in computational models defined from patient imaging and are therefore collectively referred to as model-based dose calculation algorithms (MBDCAs) (6). Because of the complexity of MBDCA algorithmic implementation, the association of their results to an image-based computational model and the use of basic input data that are not accessible by the clinical end users, dosimetry testing for acceptance, commissioning, and quality assurance purposes can no longer rely on verification of data entry and simple spreadsheet calculations, as for TG-43-based TPSs. Appropriate testing procedures are therefore required to establish acceptable uncertainty levels and ensure that uniformity of practice is maintained at a standard analogous to that achieved with TG-43-based TPSs.

These testing procedures can be experimental or computational. Experimental testing procedures, ranging from audits (7, 8) and end-to-end processes (9−11) to *in vivo* dosimetry (12), have been proposed for brachytherapy. Besides rarely associated with heterogeneous models (9, 11), experimental testing is admittedly laborious, it cannot dissociate TPS from other sources of uncertainty (e.g., source strength calibration), and it is often characterized by increased uncertainty or a resolution that is limited with regard to highlighting TPS uncertainty at all parts of a phantom geometry. Therefore, early work on the validation of MBDCA results was based on computational tests prepared using Monte Carlo (MC) simulation dosimetry (13−15), and MBDCA commissioning based on reference dose distributions and test case plan data to be made available via the web has been proposed (6).

In this regard, a test case comprises:

1. A computational model in Digital Imaging and Communications in Medicine (DICOM) format so that it can be imported into any TPS using an MBDCA.
2. A treatment plan for the computational model prepared using a TPS using an MBDCA.
3. A three-dimensional reference dose distribution calculated in the computational model using information parsed from the treatment plan exported from the TPS using an MBDCA in DICOM radiation therapy (RT) format.

Users can then import the model and plan, obtain their MBDCA results, and compare them to the reference dose distribution using either TPS-embedded tools or third party software.

Advanced clinical users in large, research-oriented facilities could use software available for the foolproof configuration of MC input files from DICOM RT plan data, such as ALGEBRA (16), BrachyGUI (17), AMIGOBrachy (18), or BrachyGuide (19), to prepare a computational test case from any clinical case. This would require that a benchmarking procedure is first performed to validate the accuracy of their reference dose distribution. Standard clinical users on the other hand rely on the availability of test cases and could further benefit from the DICOM RT viewer and dose comparison features of brachytherapy dedicated software such as AMIGOBrachy (18) and the latest version of BrachyGuide (19).

This work presents the design and implementation of a commissioning and quality assurance testing procedure based on computational dosimetry. Three computational models were developed (a homogeneous water sphere, a water sphere with embedded cubic tissue heterogeneities, and a partial breast irradiation patient). Different treatment plans were prepared for these models using the two commercially available TPSs that currently include an MBDCA option (BrachyVision, Varian Medical Systems, Palo Alto, CA and Oncentra Brachy, Elekta Brachytherapy, Veenendaal, the Netherlands). The same source, supported by both systems, was used (20), and care was taken in that the treatment plans prepared using the two TPSs were identical, so that only one reference dose distribution is required for each test case. This facilitates the assessment of uniformity of practice when different TPSs are used. Reference dose distributions were obtained using the Monte Carlo N-Particle (MCNP) general purpose code with input files prepared using BrachyGuide (19). The comparison of reference data to MBDCA results of the two TPSs, performed using the dose distribution comparison capabilities of BrachyGuide, is also presented and discussed.

The data and the tools presented in this work are available via the web (http://www.rdl.gr/downloads) and can serve as a benchmark for advanced clinical users developing their own tests, a complete commissioning procedure for new adopters of currently available TPSs using MBDCAs, a quality assurance testing tool for future updates of already installed TPSs, or as an admission prerequisite in multicentric clinical trials.

Methods and Materials

Development of test case computational models

Model 1: homogeneous water sphere

In contrast to TG-43-based TPSs that rely on precalculated dosimetry data, MBDCAs make use of source geometry, materials, and other basic input data, as well as ray tracing and spatial discretization operations (5). The first test to which MBDCAs are subjected is therefore, arguably, the calculation of the dose rate distribution around a single HDR source in a homogeneous water geometry (13, 14, 20), which is referred to as a Level 1 commissioning test in the TG-186 recommendations (6). Hence, the first model prepared for the development of test cases