A software tool for 3D dose verification and analysis

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Abstract. The main recent developments in radiotherapy have focused on improved treatment techniques in order to generate further significant improvements in patient prognosis. There is now an internationally recognised need to improve 3D verification of highly conformal radiotherapy treatments. This is because of the very high dose gradients used in modern treatment techniques, which can result in a small error in the spatial dose distribution leading to a serious complication. In order to gain the full benefits of using 3D dosimetric technologies (such as gel dosimetry), it is vital to use 3D evaluation methods and algorithms. We present in this paper a software solution that provides a comprehensive 3D dose evaluation and analysis. The software is applied to gel dosimetry, which is based on magnetic resonance imaging (MRI) as a read-out method. The software can also be used to compare any two dose distributions, such as two distributions planned using different methods of treatment planning systems, or different dose calculation algorithms.

1. Introduction

Advanced radiotherapy technologies, such as intensity-modulated radiotherapy (IMRT) and volumetric modulated arc therapy (VMAT), can provide considerable improvements to the result of radiotherapy both in terms of maximising the therapeutic effect of dose distribution on tumour, and minimising its damaging effect on surrounding healthy tissues and organs at risk (OAR). The increasing complexity of irradiation techniques has driven the development and adoption of 3D dosimetery methods, in order to optimise treatment planning and delivery systems, as well as to quality-assure their functionality. The adoption of 3D dosimetry methods has been increasing over the last decade [1, 3]. However, software applications (both freeware and commercial) that are used for dose evaluation and quality assurance (QA) purposes are primarily based on 2D evaluation methods. These 2D evaluation methods are prone to error in evaluating the accuracy of a particular dose distribution, mainly because of the mismatch that can happen in selecting the corresponding slices from the dose distribution volumes being compared.

In principle, QA based on 3D verification is assumed to provide more quality indicators for further analysis. Also, it makes it possible to define tolerance criteria in 3D in order to account for setup inaccuracies of the dosimeter phantom and/or detector. In order to derive the full benefits of using the 3D dosimeter, it is essential to use a software tool that provides analysis and evaluation results based on 3D methods and techniques. In fact, there is no software solution that provides comprehensive 3D dose evaluation and analysis. In this paper, we present a software suite that covers a wide range of 3D

dose evaluation techniques. We have particularly applied the software to gel dosimetry, based on magnetic resonance imaging (MRI) as a read-out method [4]. In addition to comparing the measured and calculated dose distributions, the software can also be used to compare plans produced using different methods such as commercial treatment planning system (TPS) or Monte Carlo (MC) algorithms. The software has been evaluated using datasets of different radiotherapy plans and MRI gel dosimeter scans.

2. Materials and Methods

The software tool presented here was produced using the MATLAB® computing language and interactive environment (version R2011a), which provides convenient and flexible high-level language and advanced graphical capabilities including 3D rendering. Also, the C programming language was used along with OpenMP API in order to optimise the speed of complex computational processes. The analysis is presented in a friendly user interface, which allows manipulation of the settings of each type of analysis. The software accepts different data formats as an input for the analysis, including DICOM and Analyze 7.5. The tool was designed to meet the analysis requirements of MRI gel dosimetry, such as calculating R2 rate data (which is proportional to the absorbed dose), and applying calibration data to produce absolute dose values.

The software tool automatically detects and calculates the 3D deviation between the reference and evaluated dose distributions by using volume registration [5-7]. The user is informed about inaccuracies arising from sources of error such as misplacements of the dosimeter during radiation delivery or read-out stage. The user can choose whether to account for this deviation in the comparison calculations. Together with the 3D analysis methods, the software tool also provides some analysis in 2D so that the 3D evaluation methods can be compared to the more conventional 2D forms.

2.1. Evaluation methods used

The software provides both qualitative and quantitative analysis. The qualitative analysis includes various types of volume visualisation methods offered by MATLAB. The quantitative analysis includes the following: dose volume histograms (DVH), absolute dose difference, relative dose difference (either globally relative to a specific dose value or locally relative to the dose at each reference point), absolute spatial difference between each reference point and the closest point (of the same dose value) in the evaluated dataset, distance-to-agreement (DTA) test (whereby a spatial tolerance is used as a pass/fail criterion), gamma evaluation (which combines a DTA criterion with a dose difference criterion through a composite analysis) [8], gamma volume histograms [9], and gamma-angle analysis (which indicates which criterion had more influenced the calculated gamma value at each reference point) [10].

2.2. *Comparison datasets*

Three reference/evaluation 3D sample pairs were compared using the software in this paper. Sample A is a standard uniform intensity conformal treatment plan which was delivered to two MRI gel dosimeter phantoms; one was stationary during the irradiation as a reference distribution, and the other was moving to simulate human respiration whilst being irradiated at full inhalation using the respiratory gated radiotherapy technique (RGRT). Sample B is for an IMRT head and neck case, where the reference distribution was measured using MRI gel dosimetry in order to evaluate its corresponding TPS plan. Sample C is for another IMRT head and neck case with an MC calculated reference plan and an evaluated TPS plan, wherein there was no experimental uncertainty involved. All the samples share the same size of 256 mm in each direction and a voxel resolution of 1 mm, which forms cubic datasets of 256^3.

3. Results

For the entire 256^3 points and using a PC equipped with Intel i7 processor, the average calculation speed for the 3D gamma was less than 1.2 seconds. The screenshot in figure 1 shows the 3D deviation map between reference and evaluated dose distributions from sample A. For sample B an average 3D deviation of ~6mm was detected by volume registration, which may have been introduced by inaccurate positioning of the gel phantom in irradiation or read-out phases. This spatial error invalidates the entire principle of 2D evaluation, which is based on comparing the corresponding slices of the two volumes and stacking up the 2D results into a 2.5D volume. With the option to account for the spatial uncertainties selected, the proportion of points passing a 3% dose difference criterion and a 3mm DTA acceptance criterion were 88.23% and 95.71%, for the 2.5D and 3D gamma calculations, respectively. Figure 2 shows the overlapped 3D render of the planned and evaluated dose distributions from sample B. For sample C, there was no 3D deviation detected, because both datasets are for calculated plans, which did not involve experimental uncertainties. The proportion of points passing a 3% dose difference criterion and a 3mm DTA acceptance criterion were 83.44% and 98.64%, for the 2.5D and 3D gamma calculations, respectively.

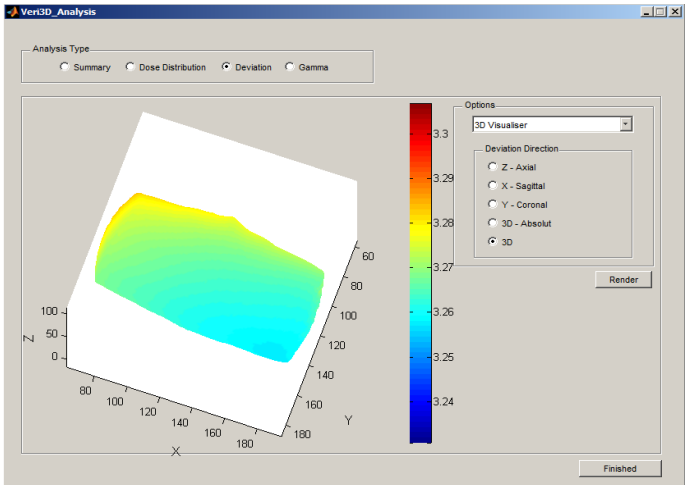

Figure 1: A screenshot showing a 3D deviation map between the two dose distributions in sample A.

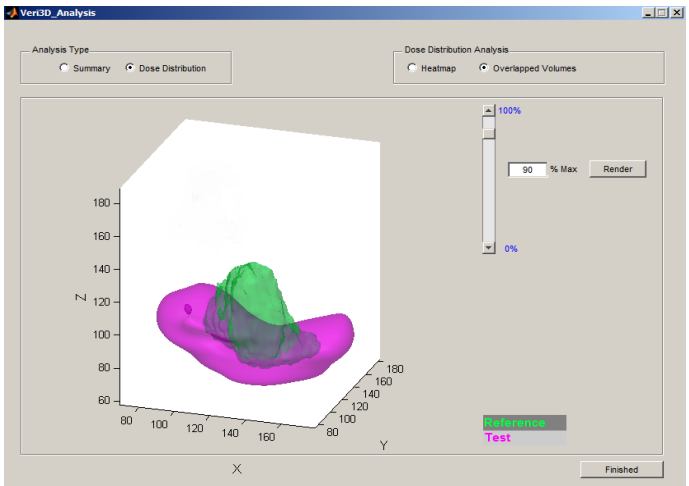

Figure 2: A screenshot for the analysis of Sample B, showing an overlay volume rendering for the reference and evaluated dose distributions at the 90% isodose surface.

4. Discussion

We present in this paper a software tool for 3D dose evaluation. In addition to 3D volume rendering for dose distributions being compared and analysis results, the software provides a catalogue of dose evaluation methods that are based on three-dimensional calculations and analysis. The settings of various analysis methods can be manipulated via a friendly graphical user interface, which allows the user to interactively examine the results of any changes in processing parameters. While the main application of the software would be to quantify the absolute accuracy of MRI gel dosimetry for planning verification, it also can be used to compare any two dose distributions. Moreover, it is planned to integrate the algorithms needed to process data obtained using other read-out techniques (such as optical CT) in future.

Without a true 3D evaluation analysis it becomes impossible to really determine and quantify the expected accuracy of gel dosimetry as a technique. It is anticipated that if this software is accepted routinely then it would become invaluable in routine QA checks. The analysis using the software to compare dose distributions which ought to be identical showed that the proportion of points passing the DTA and dose difference criteria is higher using the 3D evaluation methods than with 2.5 D analysis. This demonstrates that extending the search to points in the 3D space, rather than just in the 2D space, enhances the chance of passing the evaluation criteria. It also shows that the 3D evaluation methods account for the small movements and setup error; therefore, they produce more reliable evaluation results than the 2D evaluation methods.

5. References

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