3D Slicer Gel Dosimetry Analysis: Validation of the Calibration Process

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Abstract— **An extension tailored to dose data processing and analysis has been developed in the open source imaging application 3D Slicer to aid in routine clinical use of gel dosimetry. This extension allows for registration, calibration, and comparison of 3D gel dosimeter data (imaged using an optical CT scanner) to treatment planning data. In this work, we present the accuracy and reproducibility of the gel dosimeter calibration component of the 3D Slicer extension. We examine the consistency of the calibration curves for a range of electron beam irradiations, and the inter-user variability of the gel dosimeter calibration process.**

Keywords— **gel dosimetry, optical CT, analysis tools, dose calibration.**

I. Introduction

In recent years, advanced three-dimensional conformal radiation therapy techniques, such as intensity modulated radiation therapy (IMRT), volumetric modulated arc therapy (VMAT), and stereotactic body radiation therapy (SBRT) have rapidly developed. These new treatment techniques employ high dose modulation by using multi-leaf collimators and dynamic leaf motion, dynamic dose rate modulation, collimator rotation, and gantry rotation. These deliveries have steep dose gradients that assist in delivering high dose to the tumor, while avoiding excess dose to healthy organs and tissue. Due to the complexity of these treatments, increased treatment unit, patient specific, and process quality assurance is required to confirm that the radiation dose is delivered accurately and precisely [1,2]. For this purpose, three-dimensional radiation dosimetry tools have been shown to be promising tools for measurement and verification of radiation dose deliveries, particularly during commissioning of new treatment techniques [3,4].

Gel dosimetry consists of three-dimensional chemical systems that quantify the effects of radiation-induced chemical changes in a gelatin matrix [5]. To acquire dose distribution information, gel dosimeters are frequently read out using magnetic resonance imaging, x-ray computed tomography (CT), or optical CT. Optical CT is an attractive option for gel dosimeter read-out as it is an easy, convenient, and inexpensive method of acquiring full, 3D dose distribution information. However, gel dosimeters are not always easy to use as they require extensive post-irradiation data processing. Such processing includes registration and calibration of the gel dosimeter, then comparison between the measured gel dosimeter dose distribution and the treatment planning system's calculated distribution.

In our clinic, gel dosimeter analysis was previously performed using Matlab (Mathworks, Natick, MA) coupled with the Computational Environment for Radiotherapy Research (CERR, www.cerr.info) package for Matlab. This analysis was tedious and would take several hours to process and analyze data for a single gel dosimeter. In order to reduce analysis time and to produce a more robust analysis system, the gel dosimeter analysis workflow was implemented in 3D Slicer (www.slicer.org) by developing a custom extension [6]. The extension reduces gel dosimeter analysis time to a matter of 5-10 minutes. 3D Slicer is a good fit for gel dosimetry analysis as it is an open source and customizable computational tool used for image analysis and visualization. It features various registration techniques, slice viewers, advanced volume rendering, interactive segmentation and also has a large library of downloadable extensions. A toolbox of features tailored to radiation therapy called SlicerRT [7] is needed to run the Gel Dosimetry Analysis extension, which allows for loading of DICOM-RT data, manipulation of structures, computation and display of dose-volume histograms, dose volume comparisons, and dose distribution visualization.

A major component of gel dosimetry analysis is dose calibration, where a function relating measured optical density/attenuation to dose is determined. Accurate gel dosimeter calibration is crucial, as it dictates how useful the gel is as a clinical dosimeter. Frequently, one batch of gel is sufficient to produce several jars of gel. One of the gels from the batch is then used as a calibration gel. A number of calibration techniques exist [8,9,10], but here we present one calibration method which is performed by using electron depth dose data from ionization chamber measurements, and comparing to optical density depth dose measurements in a gel. Gel dosimeter response is roughly linear (see below), which allows for easy alignment of the two depth dose curves (Fig. 4), and then acquisition of calibration data.

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II. Materials and Methods

A. Gel dosimeter irradiation and imaging

For the validation work described in this paper, two batches of Fricke xylenol orange gel dosimeter were made. Each batch produced 2 litres of gel solution, and was poured into two 1-litre clear jars. All gels were irradiated with 6x6 cm^2 electron beams. For each irradiation, the jar was centered under the beam, the jar lid was removed, and the surface of the gel was set to SSD = 100 cm (Fig. 1). Jars were irradiated to 300 MU using 3 different beam energies: 9, 12, and 16 MeV. The 12 MeV beam irradiation was repeated for one jar of each batch.

Fig. 1 Photo of a Fricke xylenol orange gel dosimeter positioned beneath a 6x6cm^2 field electron beam applicator

Gel dosimeters were imaged using a Vista cone beam optical CT scanner (Modus Medical Devices, London, Ontario, Canada). The Vista scanner was used to acquire 410 images about a full rotation of the gel jar under 590 nm LED illumination before and then 30 minutes after irradiation. Images are then reconstructed to produce a full, high-resolution 3D volume.

B. Gel dosimetry analysis extension in 3D Slicer

We implemented a simple workflow in 3D Slicer to streamline gel dosimetry analysis. Following the landmark registration of gel dosimeter data to a planned dose distribution, step 4 of the extension features the gel dosimeter calibration component of the analysis (Fig. 2). In this step, the user imports a file containing ion chamber percent depth dose data (taken in a water tank at time of machine commissioning), and then selects a reconstructed optical gel data file (VFF file type), as displayed in Fig. 3. To acquire optical density depth dose data from the gel, optical density measurements about the central axis of the gel jar are averaged over a small region (i.e. 10 mm) to improve the signal-to-noise. An input field allows the user to specify a specific averaging radius.

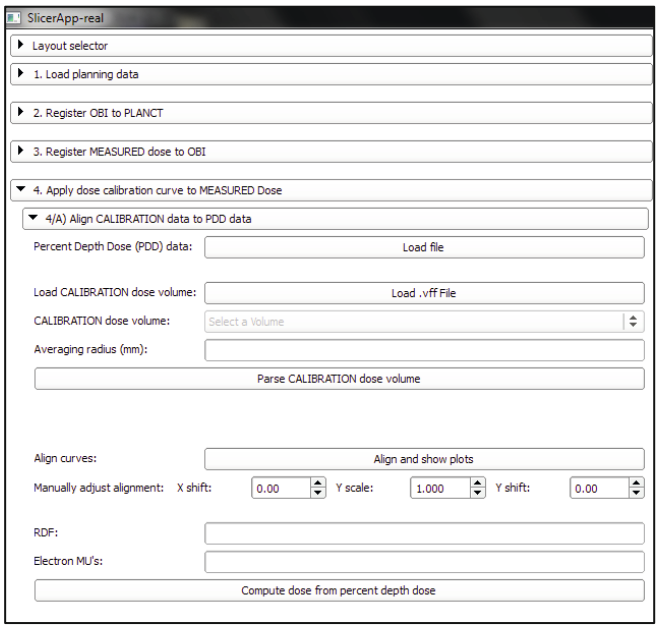

Fig. 2 A screenshot of the graphical user interface of the calibration tab in the 3D Slicer Gel Dosimetry Analysis extension

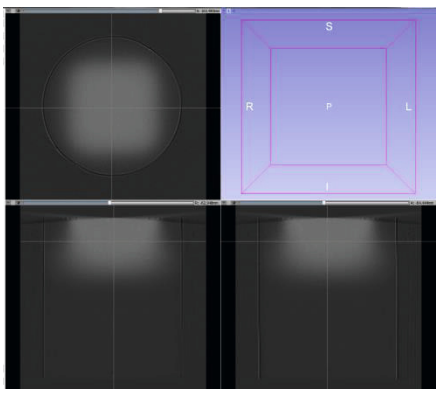

Fig. 3 Screenshot showing slices through the optical CT data of a 6x6 cm^2, 300 MU 12 MeV electron beam gel dosimeter irradiation

Once the averaged data is calculated about the central axis of the gel, the two depth dose curves are displayed and are automatically aligned using the Amoeba Minimize function [11]. The aligned plots are shown in Fig. 4, where the optical density data is temporarily scaled to visually align with the ion chamber percent depth dose data. The minimization function allows for 3 degrees of freedom when aligning the curves: Y-scaling, Y-shifting, and X-shifting.

While the Y-scaling and Y-shifting help to improve the visual representation of the data, the X-shift (depth direction) is the common parameter over which the optical density and percentage depth dose data are related. Following the automated alignment, the extension allows for manual adjustments as the automatic optimization occasionally fails to align the curves perfectly due to noisy optical depth dose data points (which can later be removed from the calibration curve).

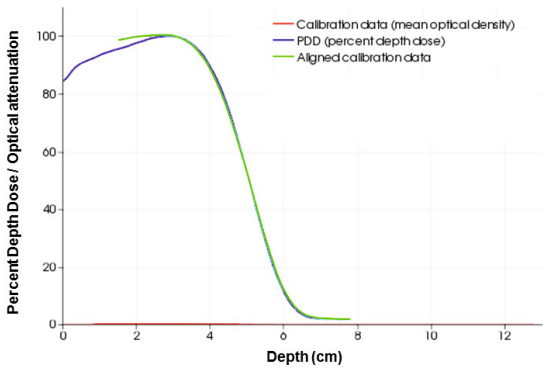

Fig. 4 Ion chamber percent depth dose data (blue), and aligned and scaled gel dosimeter calibration data (green), as displayed in the graphical user interface

Once the depth dose curves are aligned, the user inputs the relative dose factor (RDF) for the irradiated field and the number of MUs delivered to the gel. Using these parameters and the aligned depth dose curves, the percentage depth dose is converted to an absolute dose value, and is then paired with the un-scaled optical density values. Following this, the user can then select what portion of the curves they wish to use to produce the calibration line (Fig. 5).

The calibration data points are fit using a linear function, however the extension also permits fitting with a higher order polynomial. The calibration data and fit relating optical density to dose is then displayed.

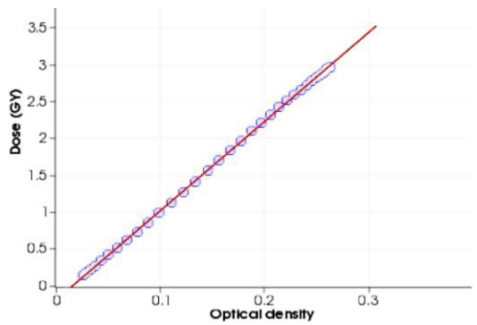

Fig. 5 Optical density and dose calibration data plotted and fitted using a linear function, as displayed in the graphical user interface

C. Consistency of calibration measurements

To validate the robustness of the calibration component of this extension, each of the four calibration gel jars described in Sec. II.A. were analyzed five times. The sensitivities (inverse of the graph shown in Fig. 5) of each of the gels were determined as a mean of the five trials. The relative standard deviations of these sensitivities were also calculated.

D. Inter-user variability of calibration process

To examine the effect of inter-user variability of the gel calibration process, the analysis was performed by three different users and the sensitivities were determined for each of the four gels, and then compared. The mean sensitivity and relative standard deviation across all users are also calculated and compared.

III. Results and Discussion

A. Consistency of calibration measurements

Table 1 Mean sensitivities for electron beam gel dosimeter irradiations

Gel Batch	Electron Beam Energy (MeV)	Mean Sensitivity (cm^{-1} Gy^{-1}) ± Relative Standard Deviation
A	9	0.0840 ± 0.1%
A	12	0.0830 ± 0.1%
B	12	0.0849 ± 0.1%
B	16	0.0872 ± 0.1%

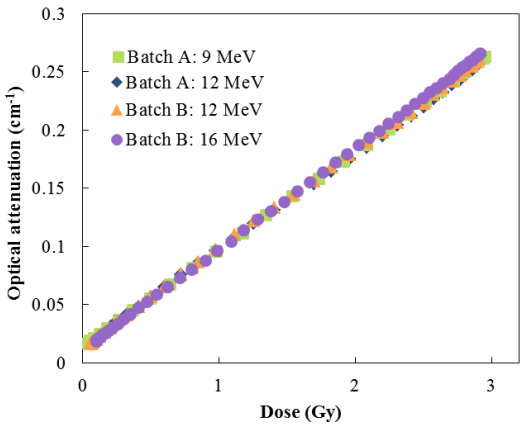

Fig. 6 Mean calibration curves for each gel, averaged over five calibration trials, showing good agreement between all four calibration gels

As shown in Table 1, calibration sensitivities are consistent over five trials, with a relative standard deviation of 0.1%. A mean sensitivity of 0.0848 cm^{-1} Gy^{-1} was calculated across all gels with a relative standard deviation of 2%.

B. Inter-user variability of calibration process

Table 2 Inter-user variation of gel sensitivities for three different users. Individual user determined sensitivities, mean sensitivities, and relative standard deviations are presented for each gel

	Sensitivities (cm^{-1} Gy^{-1})			
Beam Energy (Gel Batch)	User 1	User 2	User 3	Mean ± Relative Standard Deviation
9 MeV (A)	0.0839	0.0841	0.0841	0.0840 ± 0.1%
12 MeV (A)	0.0828	0.0836	0.0829	0.0831 ± 0.5%
12 MeV (B)	0.0841	0.0837	0.0847	0.0842 ± 0.6%
16 MeV (B)	0.0871	0.0870	0.0872	0.0871 ± 0.1%

As presented in Table 2, the mean sensitivities for the various gel irradiations do not vary more than 0.6% between the three users. These sensitivities also align well with the consistency study results presented in Table 1. This is promising as it shows that various users can easily achieve highly reproducible and precise calibration results using the Gel Dosimetry Analysis extension.

IV. Conclusions

In this work, the basic process of performing gel dosimeter calibration using the 3D Slicer Gel Dosimetry Analysis extension is presented. Consistency of measurements for a single user examining four different gel irradiations is shown to have high reproducibility and precision. Calibration measurements between users were determined to have low variation, showing that multiple users can easily achieve similar calibration results and that the calibration approach we have implemented in 3D Slicer is robust. Overall, the calibration step of the 3D Slicer Gel Dosimetry Extension makes gel dosimeter analysis about 20 times faster than the previous approach and more consistent.

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