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3D tomodosimetry using scintillating fibers: proof-of-concept

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Abstract. We present a novel, high-resolution 3D dosimeter based on the tomographic acquisition of the dose using long scintillating fibers. This study aims to demonstrate the concept of the dosimeter with simulated acquisitions using the input dose from Pinnacle³. The dosimeter is composed of concentric, cylindrical planes in which scintillating fibers are placed at different angles between the fiber and the cylindrical plane. Upon a complete rotation of the device around its central axis, the incident dose distribution on the cylindrical planes can be reconstructed using tomographic reconstruction algorithm. The 3D dose in the dosimeter can then be interpolated from the cylindrical 2D dose distributions. Using a simulated acquisition composed of two concentric cylindrical planes of 36 and 32 fibers each, we achieve below 1% local dose difference between the reconstructed 3D dose and the expected dose from Pinnacle³ in the high dose, low gradient region of the volume encompassed inside the innermost cylindrical plane. The results show the potential of the method to perform high-resolution 3D dose measurements of both square and IMRT fields.

1. Introduction

Modern dose delivery techniques such as IMRT, VMAT and tomotherapy can produce dose distribution of very high conformity and complexity. These treatment modalities require a comprehensive, patient-specific quality assurance usually performed using 2D or 3D dosimetry of the incident beam [1]. Scintillating fibers (or plastic scintillation detectors) present numerous dosimetric advantages for volumetric (3D) dosimetry such as water-equivalence, which enable the 2D or 3D arrangement of detectors without perturbation of the incident beam [2, 3, 4, 5].

The main disadvantage of using punctual detectors to perform 3D dosimetry is the high number of such detectors required to cover a whole volume with a high density of detectors. To circumvent this issue, we developed the concept of tomodosimetry (the short for tomographic dosimetry), where scintillating fibers in the length of 10 to 20 cm are used to perform a tomographic acquisition of the incident dose distribution. A first application to 2D dosimetry has shown the potential of tomodosimetry to perform accurate, high-resolution dosimetry using a relatively little number of detectors [6].

In this work, we extend the concept of tomodosimetry to 3D dosimetry of external beam radiotherapy by performing the tomographic acquisition of the dose inside concentric, cylindrical plane of a phantom. The aim of this study is to evaluate the capacity of tomodosimetry to reconstruct 3D dose of both square fields and IMRT segments. To this end, light acquisition from each scintillating fiber was simulated using 3D input calculated with Pinnacle³.



2. Methods and materials

2.1. Cylindrical tomography

All simulated fibers were confined into cylindrical planes (see figure 1) at a fixed distance from the axis of rotation of the cylinder volume. In order to perform a tomographic acquisition of the incident dose distribution, each fiber was placed at an angle Φ with respect to its cylindrical plane. As such, the sum of the light acquisition by a single scintillating fiber upon rotation of the cylinder volume around its central axis represents a projection of the dose deposited in the cylindrical plane at the angle Φ . Using many such scintillating fibers, multiple projections at different angles Φ can be acquired simultaneously with a single 360 degrees rotation of the cylinder.

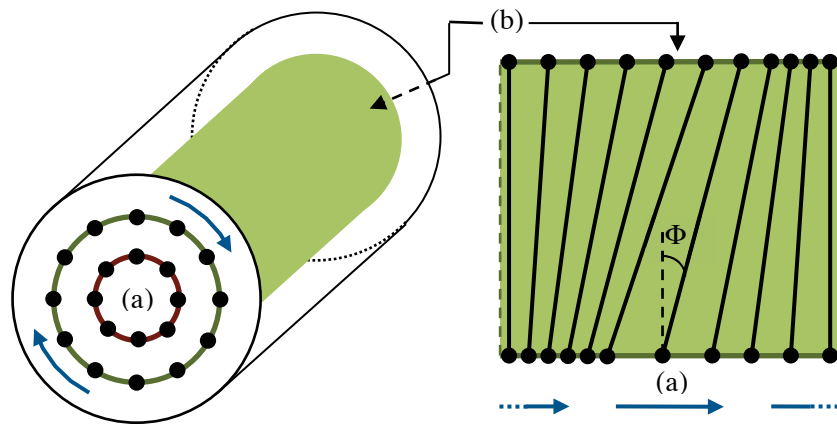


Figure 1: Scintillating fibers disposition in the phantom. Blue arrows indicate the direction of rotation. The radiation is expected to come from the figure top. Fibers are placed on the surface of one or more cylindrical volume (green, left). The angle Φ of each fiber on this surface is variable (right), allowing for tomographic acquisition of the dose following the rotation of the cylinder around its central axis.

2.2. Simulated acquisition and reconstruction

We simulated the tomographic dose acquisition using the 3D dose from Pinnacle³ computed for a square field ($10 \times 10 \text{ cm}^2$) and an IMRT segment from a head-and-neck plan. We used two concentric cylindrical planes of radius 3.75 and 7.5 cm and length 20 cm. The outer cylinder plane was composed of 36, 1 mm diameter scintillating fibers oriented at an angle Φ (see figure 1) ranging from -45 to 45 degrees by steps of 5 degrees. The inner cylindrical plane was composed of 32 scintillating fibers oriented at an angle Φ ranging from 0 to 45 degrees by steps of 5 degrees. We further considered a scintillating fiber light acquisition in 5 degrees steps of the whole cylinder volume around its central axis (following the blue lines from figure 1), and reconstructed the 2D dose distribution at a resolution of $1 \times 1 \text{ mm}^2$ on each cylindrical plane using an iterative reconstruction algorithm used in previous work [5]. The 3D dose was then interpolated at a resolution of $1 \times 1 \times 1 \text{ mm}^3$ in the cylindrical volume encompassed by one or both cylindrical plane, taking into account the $1/d^2$ decay of the dose (d = distance from the source).

3. Results

The reconstructed dose distribution on the inner cylindrical plane is presented in figure 2 for the IMRT segment. The angular position of 0 degree represents the top of the cylinder (i.e. the part closer to the incident beam), while the angular position of 180 degrees represents the bottom of the cylinder. Since the dose distribution is cylindrical, the left side (-90°) and the right side (270°) of the plane are coincident. In the same figure, the dose difference with respect to the input dose from Pinnacle³ is shown for the same field. Namely, the dose reconstruction achieves a mean dose difference of 0.45%

of the maximum dose in the high dose ($D > 0.5D_{\max}$), low gradient ($\Delta D < 0.01D_{\max}$) region of the field. Similar accuracy is seen in the outer cylindrical plane for the same field (mean dose difference = 0.54%) and in both cylindrical planes of the square $10 \times 10 \text{ cm}^2$ field (mean dose difference = 0.11% (inner plane) and 0.19% (outer plane)).

A summary of the 3D dose differences for the whole cylindrical volume is presented in Table 1 for both the square field and the IMRT segment. The mean dose difference in the high dose ($D > 0.75D_{\text{isocentre}}$), low gradient ($\Delta D < 0.01 D_{\text{isocentre}}$) region of each field was better than 0.9% of the local dose in the volume located inside the inner cylinder, while the mean local dose difference was better than 1.2% in the volume comprised between the two cylindrical volumes. The 3D dose computed at the isocentre plane (i.e. the plane at 100 cm from the source) for the IMRT segment is shown in figure 3, along with the dose difference with respect to Pinnacle³. In this case the mean dose difference in the high dose ($D > 0.5D_{\max}$), low gradient ($\Delta D < 0.01D_{\max}$) region of the plane was of 0.76% of the maximum dose and the 3%/3mm gamma test pass rate was of 97.9% of the dose pixels above 10% of the maximum dose. Even better results are observed for the $10 \times 10 \text{ cm}^2$ field, namely a mean dose difference in the high dose, low gradient region of the plane of 0.57% and a 3%/3mm gamma test pass rate of 100%.

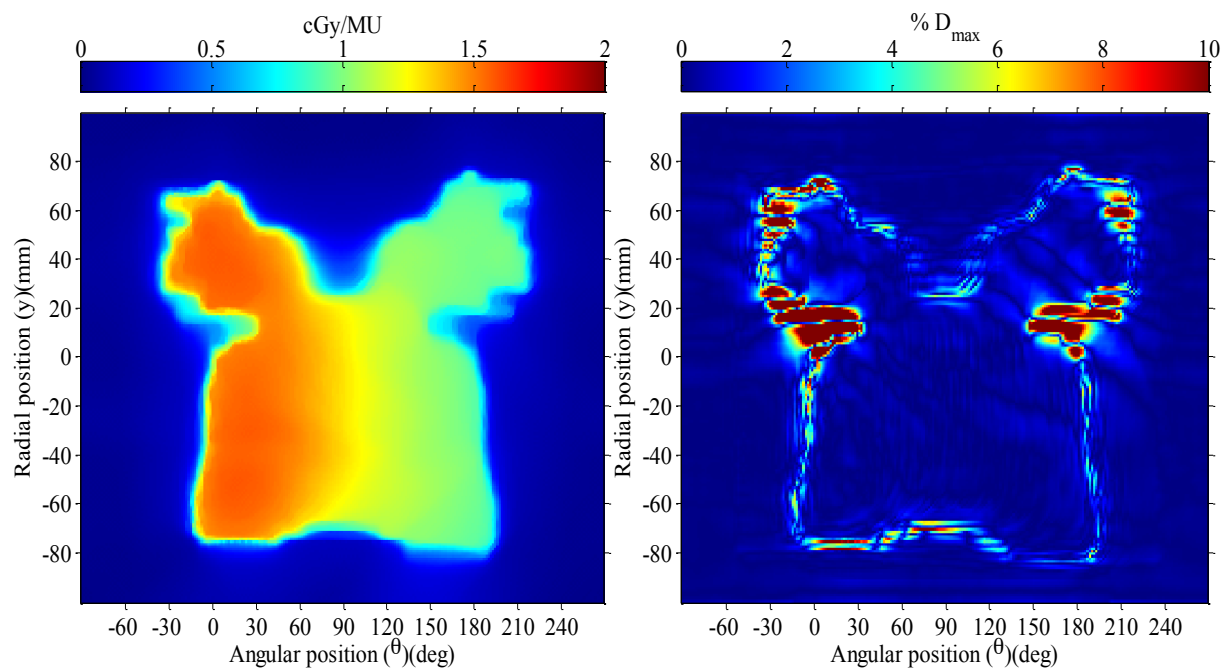


Figure 2: Left: $1 \times 1 \text{ mm}^2$ dose reconstruction of the IMRT segment on the inner cylinder plane (radius = 3.75 cm). Right: dose difference with respect to the input dose from Pinnacle³. The reconstructed dose achieved a gamma test pass rate of 99.2% (3%/3mm, $D > 0.1D_{\max}$) and a mean dose difference of 0.45% (high dose low gradient region of the field).

4. Discussion and conclusion

In this work, we have presented a proof-of-concept of a 3D dosimeter based on the tomographic acquisition of the incident dose on two concentric cylindrical planes. Simulation of light acquisition and dose reconstruction were performed and compared to the input dose of Pinnacle³. The obtained results demonstrate the potential of the proposed method to achieve 3D high-resolution dosimetry of both square and IMRT fields.

Table 1: Dose difference computed inside the cylindrical volume. The inner cylinder region refers to the volume encompassed inside the innermost cylindrical dose plane, while the outer cylinder region refers to the region between the two concentric cylindrical dose planes.

Field		10x10 cm ²		IMRT segment	
3D region		Inner cylinder	Outer cylinder	Inner cylinder	Outer cylinder
Mean Absolute local dose difference (%)		0.54	1.12	0.84	1.01
Percentage of pixel under a local dose difference of	1%	94.0	70.0	81.7	75.1
	2%	95.8	88.6	93.4	91.1
	3%	96.5	96.3	96.1	96.4

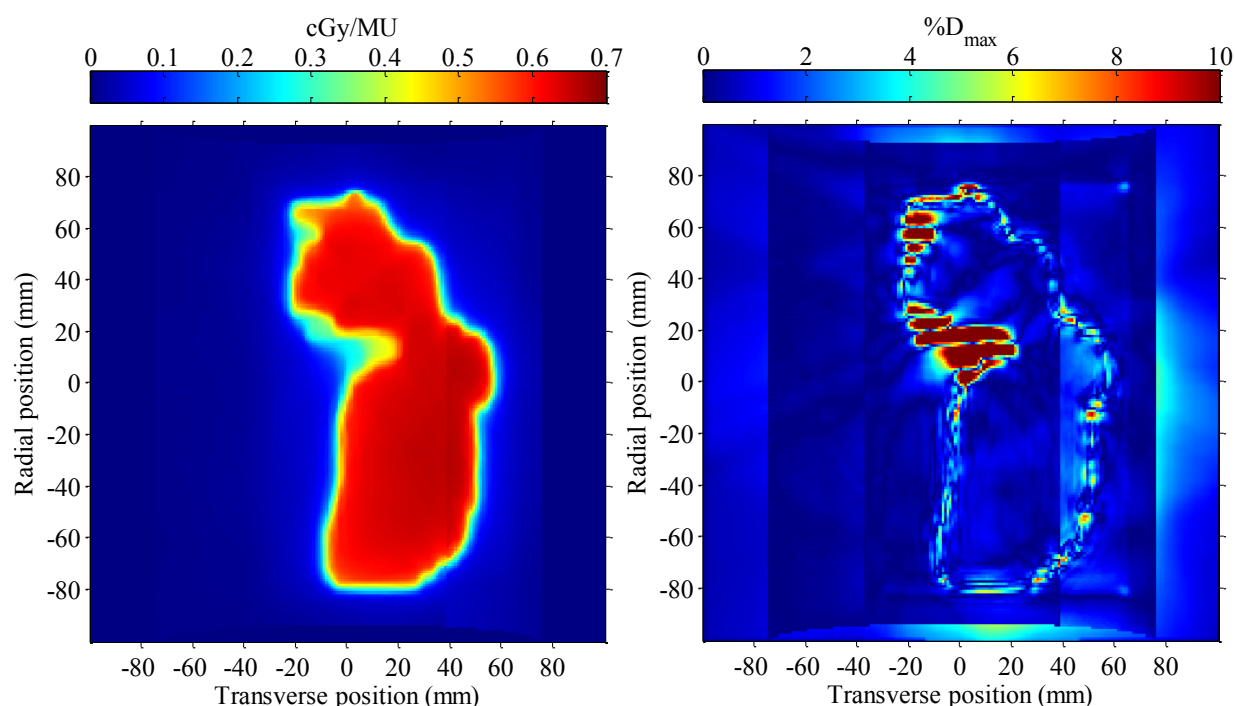


Figure 3: Left: 1x1 mm² 3D dose reconstruction of the IMRT segment on the isocentre plane (source-to-plane distance = 100 cm). Right: dose difference with respect to the expected dose from Pinnacle3. The reconstructed dose achieved a gamma test pass rate of 97.9% (3%/3mm, D > 0.1D_{max}) and a mean dose difference of 0.76% (high dose low gradient region of the field).

5. References

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