Introducing dynamic dosimaging: potential applications for MRI-linac

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Abstract: The new era of intra-fraction dose tracking in radiation therapy delivery demands new dosimetry methods, whereby a moving frame of reference as a function of time may be required. This introduces a new paradigm into radiation therapy dose verification. The term we propose to describe this is *dynamic dosimaging*, which by our definition is tracking the location of a dosimeter array in real time during on-line radiation dose acquisition.

1. Introduction

As described by Ernest Rutherford: "Radiation may be investigated by two methods, one depending upon the action of the photographic plate and the other on the discharge of electrification ... much more rapid than the photographic method and admits of fairly accurate quantitative determination." [1]. We use ancestral versions of this in the form of radiochromic film or 3D gel formulations [2, 3], and ionisation chambers or various semiconductor dosimeters, respectively [4, 5].

A dosimeter can be defined generally as any device that is capable of providing a reading that is a measure of the absorbed dose deposited in its sensitive volume by ionizing radiation [6, 7]. Strictly, radiation dosimetry (or simply "dosimetry") deals with the measurement of the absorbed dose or dose rate resulting from the interaction of ionising radiation with matter [8]. The units of dose in radiotherapy are the Gray (Gy) [9]. We increasingly compare in-beam dose maps with computer-predicted dose maps.

Imaging is the representation or reproduction of an object's form, especially a visual representation (i.e. the formation of an image). We are progressively using dosimetry maps (i.e. images or pictures) of the dose distribution at a dose plane usually, but not exclusively, perpendicular to beam delivery. Just as we call X-ray and CT anatomical information images, we propose that we start calling a dose map a 'dose-mage', or following the dosimeter convention and instead dropping the 'e', i.e. a 'dosimage'. The method of acquiring processing and reproducing these images over time or over a snap shot in time would be given the name 'dosimaging'.

Examples of typical dosimage acquisitions would be an Electronic Portal Imaging Device (EPID) or dosimeter array acquisition of a pre-patient IMRT delivery. Different representations of dosimage display would include dose as a colour wash, isodose map or pixelated dose map (grey scale or colour).

As radiotherapy technology improves, we are witnessing advanced techniques of delivery. Static gated delivery is the first step beyond static delivery. The most elegant and time efficient systems involve dynamic tracking dose delivery systems, which follow the tumour motion and hence encapsulate the tumour with dose. This is called intra-fraction dose tracking or dynamic dose delivery. It enables the dose margin around the tumour to be reduced with an associated small treatment volume. Hence less normal tissue is treated with an associated reduction in normal tissue toxicity.

There are examples of existing technology that provide scenarios where the patient's tumour moves and is tracked dynamically by the treatment device. These include CyberKnife® or multileaf collimator (MLC) tracking with Calypso® RF tracking device [10].

As with current radiation therapy quality assurance (QA), which validates static dose delivery, we need a mechanism to validate dynamic tracking dose delivery. In order to best estimate the dose to the target using a surrogate phantom dosimeter delivery, there are two choices:

(1) Leave the detector static and re-compute the dose distribution using a movement that is simulated in a virtual reality environment (we have not tested this here).
(2) Move the detector array in the same temporal and spatial pattern that the tumour would move.

This introduces a new paradigm into radiation therapy dose verification. The term we propose for moving the detector in the tumour pattern while acquiring dose is 'dynamic dosimaging'. This describes tracking the location of a dosimeter array in real time during radiation acquisition. This is important for dynamically moving dose deliveries. In essence, the dosimeter is moving in time in the same frame of reference as that of the tumour motion. A summary defining the terms dosimaging, static dosimaging, dynamic dosimaging, and virtual dynamic dosimaging is outlined in Figure 1.
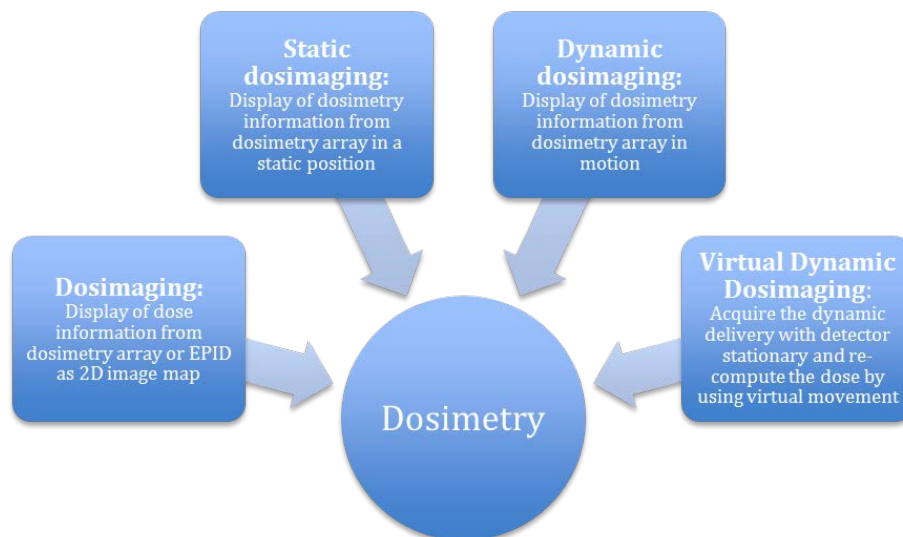

Figure 1. Summary of different definitions of dosimaging as subsets of dosimetry

Note that the dose map acquisition with the dosimeter array in a static fixed position (i.e. static dosimaging) is extremely useful for the majority of radiotherapy dose deliveries. These include IMRT, VMAT, SRT and SBRT/SABR treatments and gated deliveries. Hence leaving the dosimeter array in a static location may remain preferable perhaps for a majority of QA dosimetry. Subsequently, less normal

tissue is treated. Then, why move the dosimeter array? By moving the phantom on a platform using a typical patient breathing trace, this ensures acquisition of the ground truth dose, provided that all components of system lag (e.g. MLC tracking delay) are accounted for.

2. Methods

Whilst not so far named, we have previously demonstrated in the literature an example of dynamic dosimaging using a high resolution array dosimeter, the MagicPlate-512 (M512). This dosimeter is combined with a respiratory motion hexapod phantom that mimics and tracks lung motion during radiation acquisition in RF fields using Calypso RF tracking device [10]. The method is not necessarily restricted to this technology and there may be other devices that can or have already achieved results resembling this approach.

The essential components for a generic dynamic dosimaging system are:

(1) Platform that can move synchronously with a patient movement (usually breathing or specific individual organ motion) pattern.
(2) Array dosimeter that can be placed in-phantom on the platform
(3) A platform-dosimeter system that can mimic motion by tracking the position of tumour motion in time and space using fiducials or another tracking mechanism.
(4) Software that can record the dose with high temporal resolution in real time with respect to detector position.

Because the frame of reference of the beam's eye view is now a moving position in space and time, then the enemy of dynamic dosimaging is system latency. If the latency in time is significant compared to the movement cycle then anomalies can occur in the acquired dose distribution.

3. Results

Figure 2 presents an example of a typical static dosimage that was collected using an EPID acquisition and processing software described elsewhere [11].
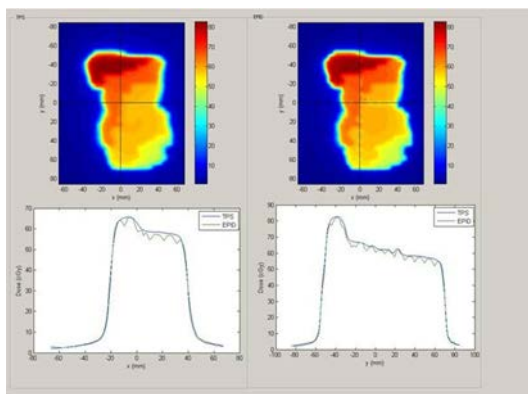

Figure 2. Static dosimage acquired using an Electronic Portal Imaging Device (EPID): Treatment planning system (TPS) dosimage (top left) and profile (bottom left) and EPID reconstructed dosimage (top right) and dose profile (bottom right).

To give a qualitative example of what can be achieved using dynamic dosimaging, Figure 3 shows a pixelated colour map of three different delivery and acquisition combinations. These detectors have been successfully placed in respiratory motion phantoms for mimicking lung motion during radiation acquisition in RF fields using Calypso RF tracking device [12].
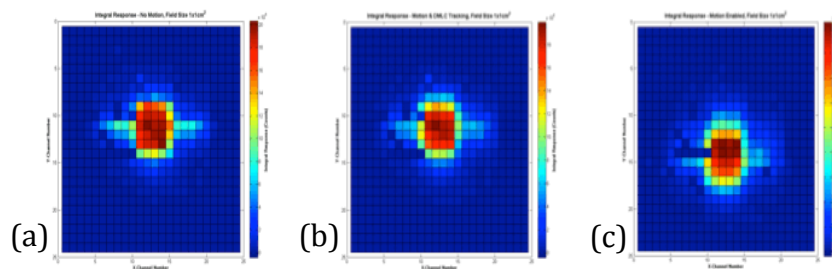
Figure 3. M512 array acquisitions, (1 × 1cm MLC) (a) static MLC, static dosimeter, (b) static MLC, moving platform, (c) moving MLC moving platform (i.e. dynamic dosimaging).

4. Discussion and Work in Progress

There are other potential methods to track the detector positions. These may include using x-ray imaging combined with tracking methods to locate the detector in time and space. These could be either using stereoscopic tracking methods such as ExacTrack® [13] or respiratory correlated cone beam CT (CBCT) [14].

We envisage this as a potential future QA method for MRI-linac dynamic tracking deliveries. Solid objects in MRI (e.g. bone, ultra-short relaxation time) are inherently difficult to visualise. In this case, one option is to place MRI fiducials on a detector array to indicate its position in space (see Figure 4). We have obtained this image using a 3 T MRI scanner. We have achieved moving and visualising the detector during a MRI acquisition.
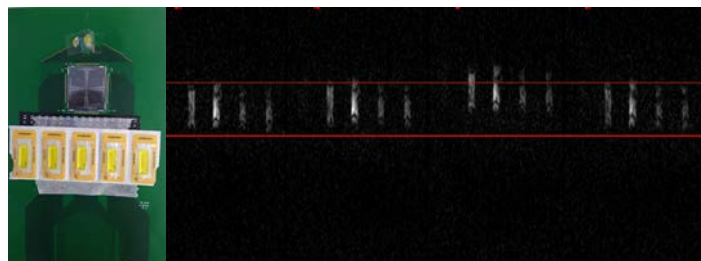

Figure 4. (a) Octa diode array with five MRI fiducial markers, (b) Fiducials tracked using MRI breathing sequence showing movement shown (i.e. 1, 2, 3, 4).

5. Conclusion

The imperative for moving a dosimeter during pre-treatment verification follows the trend toward dynamic tumour tracking. To validate dose to a moving tumour via a dynamic delivery platform or, *dynamic dosimaging*, is one emerging technique that will satisfy the requirement that the dose you see (predicted by the TPS) is the dose you get.

6. References

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