Verification of motion induced thread effect during tomotherapy using gel dosimetry

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Abstract. The purpose of the study was to evaluate how breathing motion during tomotherapy (Accuray, CA, USA) treatment affects the absorbed dose distribution. The experiments were carried out using gel dosimetry and a motion device simulating respiratory-like motion (HexaMotion, ScandiDos, Uppsala, Sweden). Normoxic polyacrylamide gels (nPAG) were irradiated, both during respiratory-like motion and in a static mode. To be able to investigate interplay effects the static absorbed dose distribution was convolved with the motion function and differences between the dynamic and convolved static absorbed dose distributions were interpreted as interplay effects. The expected dose blurring was present and the interplay effects formed a spiral pattern in the lower dose volume. This was expected since the motion induced affects the preset pitch and the theoretically predicted thread effect may emerge. In this study, the motion induced thread effect was experimentally verified for the first time.

1. Introduction

Lung tumors may move due to breathing which can result in differences between the planned and delivered absorbed dose distributions [1]. When respiratory motion is present and not taken into account, for example with increased margins, dose blurring will occur. During advanced radiotherapy such as volumetric modulated arc therapy (VMAT) and intensity modulated radiation therapy (IMRT) breathing induced interplay effects may also occur, which are the differences between planned and delivered absorbed dose that arise from a mismatch between the target and the MLC because of motion [1]. This may cause unpredictable cold and hot spots in the delivered dose distribution. For helical tomotherapy (Accuray, CA, USA) [2] not only the target and MLC move, but also the treatment couch and the radiation source, making the interplay effects even more complex.

In tomotherapy, it is well known that the helical beam junctioning gives rise to a dose ripple described as a "thread effect" [3]. In order to minimize the inherent thread effect, the pitch is set so that the couch travel distance for one (or an integer number of) gantry rotation(s) equals the field width, adjusted for the effects of scattering and beam divergence [3]. In the case of a moving phantom, the combined travel distance of the couch and the phantom may invalidate the pitch setting, and a motion induced thread effect may emerge [4]. This effect can be substantial as long as the frequency of the periodic phantom motion is the same as (or a multiple of) the gantry rotation frequency. However, if the periods mismatch, or if there are random phase shifts, such as in real breathing motions, the effect will decrease [4]. Indeed, while motion induced dose blurring effects have been

demonstrated in helical tomotherapy, both by film measurements [5-6] and diode detector arrays [7], thread effects have so far not been experimentally verified.

Interplay effects have previously been investigated for IMRT and VMAT using various methods [8-12]. In this study we take advantage of the very high spatial resolution in three dimensions that the polymer gel detector system provides to measure the motion induced thread effect during tomotherapy. In our previous work it has been shown that polymer gel is a feasible detector for 3D dose verification of dynamic radiotherapy [9, 13-15]. A definition of the interplay effect was proposed as the relative 3D absorbed dose difference between the volumes obtained from the measurement during phantom motion and the measurement to a stationary phantom convolved with the motion function of the moving platform [9].

The aim of this study was to investigate any breathing interplay effects during tomotherapy delivery and identify the expected motion induced thread effect using polymer gel dosimetry.

2. Material and methods

2.1 Polymer gel phantoms

The normoxic polyacrylamide gel (nPAG) used in this study contained 89% w/w ultra-pure deionised water, 3% w/w acrylamide, 3% w/w N,N'-methylenebisacrylamide, 5% w/w gelatine and 10 mM tetrakis(hydroxymethyl)-phosphonium chloride (chemicals from Sigma Aldrich, Germany). Magnetic resonance imaging (MRI) using a 1.5 T unit (Siemens Symphony) was performed about 24 hours post-irradiation. The mixing- and read-out procedures are described elsewhere [14]. MATLAB 7.4.0 was used for image processing and 3D rendering. The R2 data of the irradiated gel phantoms [16] was converted to relative absorbed dose using background subtraction and normalization in a region of homogenous dose [17].

One single batch of gel was used for all experiments. Identical 1.3 liters circular gel phantoms (Ø 10 cm) were used for both measurements during motion and in static mode. An identical un-irradiated gel phantom was used to acquire a background value. Gel vials irradiated to known absorbed doses were used to assure the linearity of the gel dose response.

2.2 Tomotherapy treatment plan and delivery

The treatment plan was calculated with TomoTherapy PlanningStation (Accuray, CA, USA) using 1688 MU (3 Gy) with a beam width of 2.5 cm and a planning modulation factor of 1.4. The total treatment time was 125.2 s with a gantry rotation period of 12 s. The pitch was set to 0.215 to minimize the inherent thread effect. To simulate tumour movement caused by respiratory motion, the gel phantom was positioned on a programmable motion device (Hexamotion, ScandiDos, Uppsala, Sweden) which was set to carry out sinusoidal motion in the superior–inferior (SI) direction with a peak-to-peak distance of 20 mm and a period of 6 seconds. Since the end-to-end distance was traveled in 3 s, this was expected to introduce a motion induced thread effect with an axial advance of 20 mm for a quarter of a complete turn. The delivery was repeated for a second gel phantom with the motion device turned off, i.e. the gel in static mode. The 90% isodose volume for the static gel was 22.6 cm^3.

2.3 Definition of interplay effect

The interplay effect was calculated as the relative 3D absorbed dose difference between the volumes obtained from the measurement during phantom motion and the measurement to a stationary phantom convolved with the motion function of the moving platform. The relative absorbed dose difference between the measured and convolved dose matrices was calculated by voxel-by-voxel subtraction as described earlier [9].

Table 1. The mean value and standard deviation (SD) of the comparison of the different dose distributions.

		Mean value ± 1 SD (%)
95 % isodose volume	Static gel vs TPS	1.0±1.0
	Static gel vs dynamic gel	5.5±3.2
	Dynamic gel vs convolved static gel	-0.5±2.2
50 % isodose volume	Static gel vs TPS	2.5±1.4
	Static gel vs dynamic gel	4.9±5.2
	Dynamic gel vs convolved static gel	0.0±4.6

3. Results and discussion

There was good agreement between the static gel and the TPS while there was a difference in the dose distribution between the dynamic and static gels and the dynamic and convolved static gels (table 1, figure 1). The expected dose blurring was clearly shown comparing the dynamic and static dose distributions. Differences still existed comparing the dynamic and convolved static dose distributions and hence interplay effects were present. These dose differences formed a spiral pattern in the lower dose volume, which was identified as the thread effect with an axial advance of 20 mm for a quarter of a complete turn (figure 2), which was predicted theoretically. The absorbed dose linearity test of the gel batch resulted in R^2= 0.998.

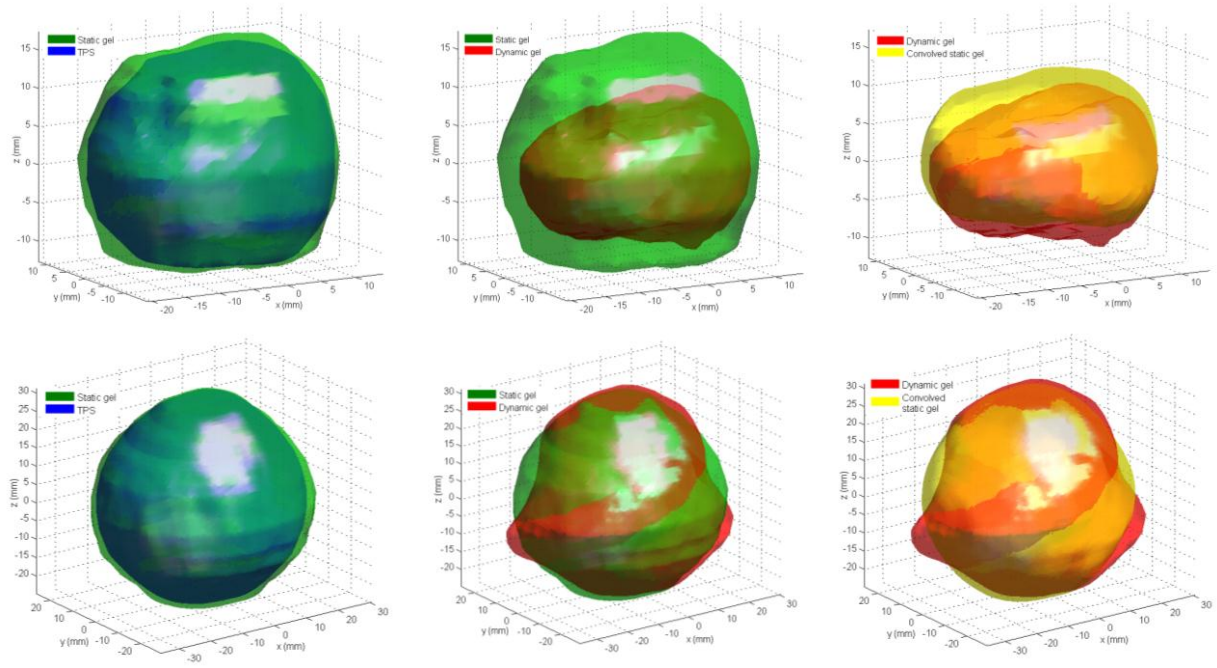

Figure 1. The 95 % isodose surfaces (top) and the 50 % isodose surfaces (bottom) for the static gel and TPS (left), the static gel and dynamic gel (middle) and the dynamic gel and the convolved static gel (right). The motion was induced in the z (SI) direction.

4. Conclusion

In this study, both the expected dose blurring effect but also breathing interplay effects were shown for a tomotherapy treatment of a small target in motion using gel dosimetry and a motion device. For volumes receiving lower absorbed dose over- and under-dosed volumes appeared in a spiral form. Thus the motion induced thread effect was experimentally verified for the first time.

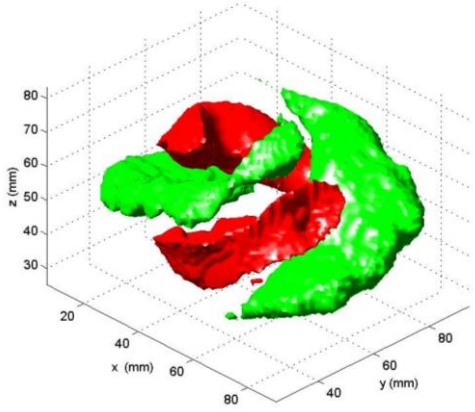

Figure 2. The surface of the voxels enclosed by the 50 % isodose volume with an absorbed dose difference of more than 5% (green) and less than -5% (red) between dynamic gel and convolved static gel, showing a spiral pattern.

5. References

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