Cumulating static dose distributions to simulate dynamic dose distributions: an experimental study

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Introduction: The irradiation of a moving object leads to a blurred dose distribution. The "blurring effect" is characterized by an enlarged beam penumbra mainly depending on the object movement patterns. It can be obtained by the convolution of the dose distribution with a motion kernel [1]. The blurred dose distribution induced by the breathing can compromise the goal of conformal radiotherapy which tends to reduce the margins around lung tumors. Engelsman et al. evaluated the influence of tumor motion on 3D cumulative dose with a static inhomogeneous phantom [2]. They simulated respiration-induced tumor motion with an amplitude of 5mm. They found that a small amplitude of breathing motion contributed peu to the decrease of Equivalent Uniforme Dose and Tumor Control probability. In this study, we analyzed the dose deposit in an inhomogeneous moving phantom with an amplitude of 2cm. We quantified the increase of the beam penumbra. We also propose to compare measured dynamic dose distributions (DDD) with calculated and simulated DDD.

Materials and method: An inhomogeneous moving phantom, representing "a tumor in lung" was used for the study. It consisted of a 4x4x4cm^3 polyethylene insert embedded in a 12x12x12cm^3 wood phantom. The phantom was set on a moving plate which simulated respiration. The sinusoidal movement of the plate was defined by a vertical amplitude of 2cm and a 4s period (figure x). X-OmatV films were placed at the center of the phantom and were irradiated perpendicularly to the direction of the movement with a 8x8cm^2 field size of a 6MV photon beam (figure x). As the movement of the plate was modelled and split in 4 intervals of positions, we determined the duration in which the plate stayed for each interval of position. Lujan et al. validated the convolution based method to incorporate organ motion due to breathing in dose distributions [4]. The total dose received at the center of the tumor can be described according to the equation 1:

$$\bar{D} = \int T(D(t))\omega_t$$

where $\bar{D}$ is the dose at a point in the object incorporating organ motion, T the displacement of the point from the instant t to the instant t_0, $D(x,t)$ the dose at the point at the instant t and ω_t the temporal weight. In our case, we assume that the "tumor" in the phantom had a vertical motion.

After the phantom was imaged, static dose distributions (SDD) were calculated for the different positions of the moving phantom with the superposition convolution algorithm of the Xio-TPS. Dynamic dose distributions (DDD) were finally simulated by summing SDD weighted with the temporal weight according equation 1.

Different dose distributions comparisons were made at the center of the phantom:

- measured SDD from the films *versus* measured DDD from the films: to quantify the change in penumbra due to motion
- measured DDD from the films *versus* simulated DDD from the TPS: to quantify the error made by simulating a DDD with the TPS

The beam penumbra (D_{80}-D_{20} distance) was from each comparison measured.

Results: Figure x indicates penumbrae values for the different dose distributions studied. The penumbra calculated from the TPS is 1.3mm larger than the penumbra measured in the static configuration. This is due to the superposition convolution algorithm which does not accurately predict the beam penumbra, mostly in non-homogeneous media. The ratio between SDD and measured DDD from films is 0.36 and between SDD from films and simulated DDD from TPS is 0.93. These preliminary results will be completed with measurements for two other depths (interfaces of the insert).

Discussion and Conclusion: Our experimental system allowed to, first, quantify the increase of penumbra, and secondly, validate the method allowing obtaining simulated dynamic dose distribution.

References:

[1] T. Borfeld, S.B. Jiang, E. Rietzel, "Effects of motion on the total dose distribution", Seminars in radiation oncology, Vol 14, No 1, 41-51, 2004.

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[3] A. Lujan, E. Larsen, J. Balter, R. Ten Haken, "A method for incorporating organ motion due to breathing into 3D dose calculations", Med. Phys. Vol. 26(5), p715-720, 1999.

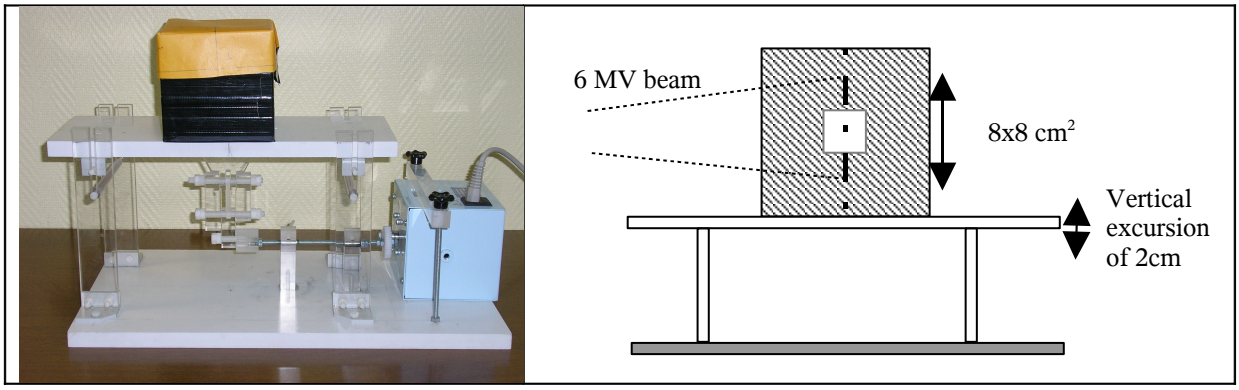


Figure x: The inhomogeneous phantom set on the dynamic plate and the irradiation configuration

Figure x: Sinusoidal curve corresponding at the displacement of the moving phantom.

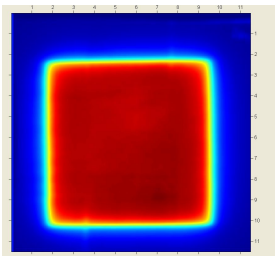
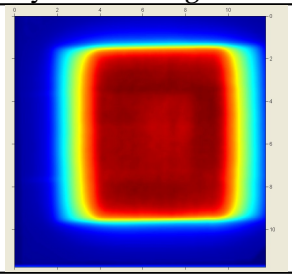
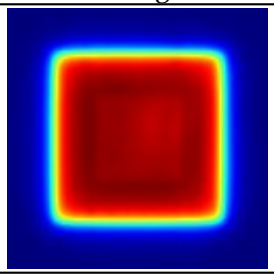
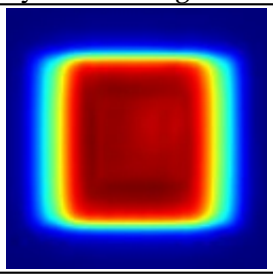
Measured dose distributions from films		Calculated dose distributions from the TPS	
Static configuration	Dynamic configuration	Static configuration	Dynamic configuration
			

Figure x: Static/dynamic dose distributions obtained at the center of the phantom from either film measurement or the TPS.

Penumbra = D_{80}-D_{20} distance in mm			
Measured		Calculated	Simulated
Film / Static	Film / Dynamic	Sup. Conv. / Static	Sup. Conv. / Dynamic
5.7	15.7	7.0	16.9

Figure x: Table of penumbra widths measured at the center of the phantom in the direction of the movement (beam perpendicular to the motion)