AbstractID: 8955 Title: 4D planning from multi phase 3D dose distribution and linear transformation on a single phase plan

Purpose: To reconstruct a 4D dose distribution from the planned dose based on one phase of a 4D-CT image and compare with results from 4D dose reconstructed from multiple phases and phantom measurements.

Method and Materials: A treatment plan was developed for a set of CT images from a single phase of a respiratory motion phantom using ADAC pinnacle TPS. The single phase reconstructed dynamic dose distribution to a coronal pane was obtained for several tumor trajectories by applying a linear transformation on the optimized dose from pinnacle. This was then compared to the dynamic dose distribution obtained by considering a weighted sum of dose distributions from plans based on eight phases of the tumor cycle. Measurements using radiochromic films were made following plan delivery on a LINAC to validate our results.

Results: Using gamma index analysis, the number of pixels exceeding a gamma index of 1 was 7% and 0% for the measured versus single phase, and the single versus multi-phase reconstructed dynamic dose respectively. This was based on a dose difference tolerance of 5% and DTA tolerance of 5mm. The effects of phase dependent weighting versus equal weighting were in general negligible on the dose distribution for the trajectories studied. Using dose difference tolerance of 3% and a DTA tolerance of 4mm, the comparison yielded 0.5%, 0.72% and 1.72% as the percentage of pixels exceeding the gamma index of 1 for sinusoidal tumor motion amplitudes of 1cm, 1.5cm and 2cm respectively.

Conclusion: There was close agreement between the two methods of reconstruction and with measurements. Recreating the dynamic dose distribution from the static dose distribution from a single CT image set can be an efficient way of accurately accounting for relative motion in a static or dynamic dose delivery and can be useful in pre-treatment verification analysis.

4D planning from multi phase 3D dose distribution and linear transformation on a single phase plan

Introduction: Optimal dose delivery for tumors associated with respiration-induced organ motion still remains a challenge in the field of radiotherapy. With the advent of 4D-CT, one can explicitly incorporate patient specific respiratory motion into treatment planning to ensure dose coverage of the target throughout the breathing cycle and to calculate the dose distributions for the target and organs at risk when respiratory motion is present during beam delivery [1]. However, since 4D plan on multiple CT images, generating about 20 times more image data than a standard planning scan, require dose calculation on multiple CT images, and require deformable image registration and methods to obtain integral dose distributions and DVHs [1,2,3], the challenges in terms of workload and data processing equipment and techniques are evident.

In this work, we present a phantom based technique for recreating the 4D dose distribution from a 3D dose distribution based on a single CT image from one phase of the tumor cycle. We then compare the dose distribution against the dynamic dose based on the consideration of multiple phases of the tumor motion cycle.

Materials and Methods:

Theory: For simplicity, we shall consider a 1-D sinusoidal tumor motion in the inferior-superior direction so that the tumor center trajectory (x, y, z) is given as (x, $A\sin\left(\frac{2\Pi t}{T}\right)$, z), where t is the instantaneous time, T is the period and A is the amplitude. Let ${}^{3D}D_r(x,y,z)$ be the 3D static dose distribution at a voxel located at (x,y,z) based on the rth phase (reference phase) and ${}^{4D}D(x,y,z)$ the corresponding 4D dynamic dose distribution. By invoking symmetry arguments on a uniform density phantom in the tumor motion direction, the 4D dynamic dose distribution can be recreated from the reference phase static dose distribution as;

$$ {}^{4D}D_r(x,y,z) = \sum_{i=1}^{N} W_i * {}^{3D}D_r[x,(y + A\sin\theta_i),z] \qquad \text{..... (1)} $$

Where $\theta_i = \frac{\Pi(2i-1)}{N}$, $N = \frac{2*A}{pixel\_width}$ and $W_i = \frac{|\sin\theta_i|}{\sum_i |\sin\theta_i|}$

N is the number of bins, chosen so as to optimally span the trajectory. W_i is a weighting function that accounts for the relative duration of a moving structure at a given location along the trajectory. The operation $\sum_{i=1}^{N} W_i$ is a linear transformation on the 3D dose matrix.

Planning and Measurements:

We used ADAC pinnacle TPS to plan on a respiratory motion phantom (Modus Medical Devices Inc. Ontario, Canada) based on one set of CT images. The optimized dose distribution was then used in equation 1 to compute the 4D dose distribution for a planar film assumed to move with the tumor center. For comparison, we generated PTV locations corresponding to 8 phases along the tumor trajectory and calculated independent planar dose distributions based on each PTV. A weighted sum of the dose distribution was then compared with the recreated dynamic dose. 4D dose distributions were calculated for various tumor trajectories. We also investigated the effect of weighting as described above versus combining the dose distribution from the multiple phases using equal weights for three amplitudes 1cm, 1.5cm and 2cm. The radiotherapy plan was delivered on the LINAC, Varian 23EX (Varian Oncology Systems, Palo Alto, CA). Measurements were made using EBT Gafchromic film (ISP, NJ) to obtain the planar dose distribution which was compared to the calculated 4D planar dose.

Results: : Using gamma index analysis, the number of pixels exceeding a gamma index of 1 was 7% and 0% for the measured versus single phase, and the single versus multi-phase reconstructed dynamic dose respectively. This was based on a dose difference tolerance of 5% and DTA tolerance of 5mm. With a more stringent tolerance for dose difference (3%) and DTA (4mm), the percent of pixels exceeding gamma index of 1 was 0.41% for the two reconstruction methods. The effects of phase dependent weighting versus equal weighting were in general negligible on the dose distribution for the trajectories studied. Using dose difference tolerance of 3% and a DTA tolerance of 4mm, the comparison yielded 0.5%, 0.72% and 1.72% as the percentage of pixels exceeding the gamma index of 1 for sinusoidal tumor motion amplitudes of 1cm, 1.5cm and 2cm respectively.

Conclusions: With knowledge of the tumor trajectory and by assuming symmetry in the direction of the tumor trajectory, we can recreate the 4D dynamic dose distribution from the 3D static dose based on a single set of CT images. The results agree well with measurements and with the dose recreated by considering multiple phases of the tumor motion. The observed variation with measurements can be greatly improved with better experimental methods image co-registration.

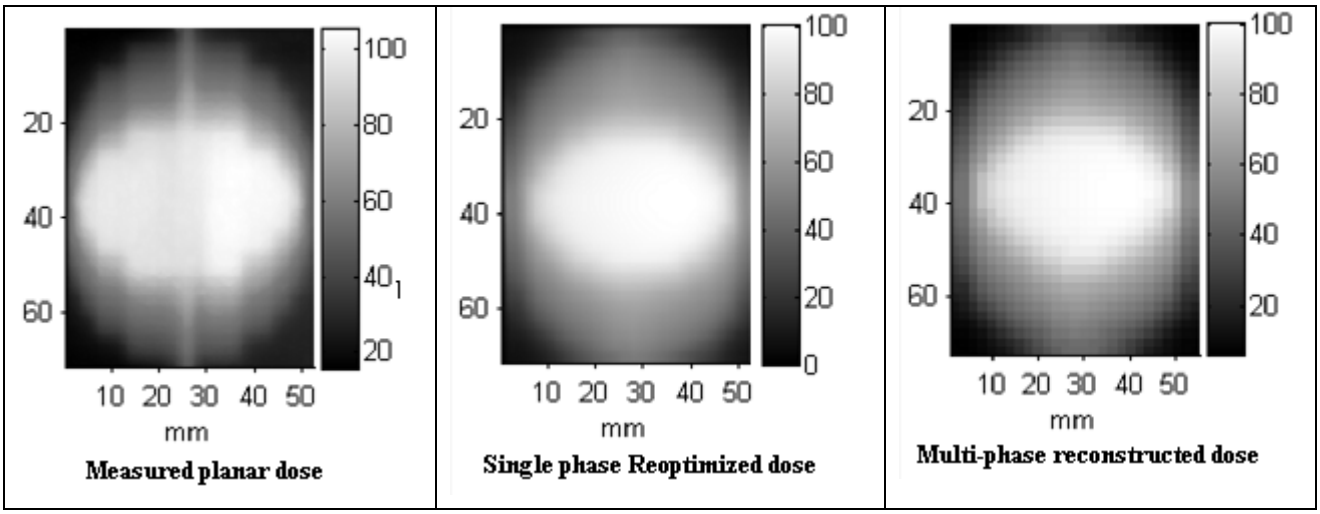

Figure 1: 4D dynamic dose from single, multi phase plans and measurements

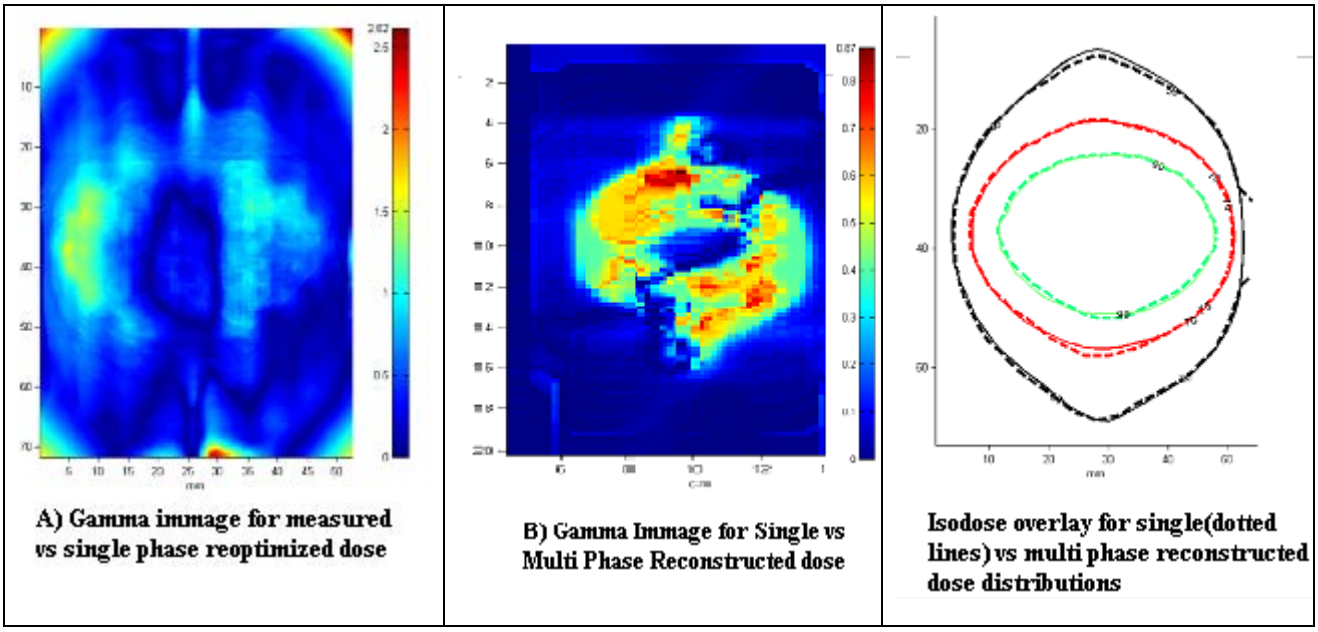

Figure 2: Gamma index analysis and isodose analysis of the various methods of 4D dose reconstruction

	A	B	B	x = (1cm)Sin(θ)	x = (1.5cm)Sin(θ)	x= (2cm)Sin(θ)
Dose Diff. Tolerance	5%	5%	3%	3%	3%	3%
DTA Tolerance	5mm	5mm	4mm	4mm	4mm	4mm
No. of pixels exceeding Gamma Index Value of 1	7%	0%	0.41%	0.5%	0.72%	1.2%

Table 1: Gamma Image analysis for image A and B (Fig.2) (Col 2,3,4) and gamma image analysis (gamma image not shown) for uniform weighting vs phase dependent weights of multi-phase dose distribution shown for tumor motion in LR direction (x=ASin(θ)) for amplitudes 1, 1.5 and 2cm (Cols 5,6,7 respectively).

References

1. Eike R., George T.Y., Noah C.C., Christopher G.W. Four-dimensional image-based treatment planning: Target volume segmentation and dose calculation in the presence of respiratory motion. Int. J. Rad Onc Biol. Phys., 61(5), 2005

2. H Alasti, Y.B. Cho, A.D. Vandermeer, A. Abbas, B. Norrlinger, S. Shubbar, A. Bezjak. A novel four-dimensional radiotherapy method for lung cancer: imaging, treatment planning and delivery. Phys. Med. Biol. 51 (2006) 3251-3267

3. P.J. Keall, S. Joshi, S.S. Vedam, J.V. Siebers, V.R. Kini. Four-dimensional radiotherapy planning for DMLC-based respiratory motion tracking. Med. Phys. 32(4), 2005