AbstractID: 10139 Title: Investigation of the dosimetric consequences based on imaging used for conventional, gated and tracking radiotherapy of mobile tumors

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Introduction

One of the goals of treatment planning is to accurately predict the delivered dose distribution in the course of radiotherapy. Therefore the plan should replicate the delivery conditions as close as possible. Conventional treatment planning systems estimate the dose distribution based on a static anatomy. For mobile tumors, because the geometry presented during treatment delivery may be different from that used in the treatment planning step, the predicted dose distribution can differ from the actual delivered dose. While the truly delivered dose may not be known, the use of four dimensional computerized tomography (4DCT) image based plans will generate a dose distribution that is close to the delivered dose since organ motion and deformation effects are accounted for. However, 4DCT image based planning require multiple CT images, generating about 20 times more image data than a standard planning scan, require dose calculation on multiple CT images and deformable image registration methods to derive the integral dose distributions and DVHs (Eike et al., 2005, Keall et al., 2005, Alasti et al., 2006). Therefore even in situations where 4DCT based planning is desired over 3D planning, lack of equipment or the increased workload associated with 4D planning may be the reason why a 3D plan is implemented. The goal of this work was to investigate the effectiveness of 3D image based plans in predicting the delivered dose for conventional, gated or tracking radiotherapy of mobile tumors. We used the dose distribution predicted by 4D planning as an approximation of the actual dose distribution deliverable in the radiotherapy procedure.

Method and Materials

Data from two patients previously treated for non-small cell lung cancer with tumor extent of motion of about 10 mm was used. For each patient and delivery, a 3D dose was estimated based on a static anatomy using the ADAC Pinnacle3® treatment planning system, version 8.0d (Phillips, Fitchburg, WI). We prescribed 60 Gy to the 70% isodose shell and renormalized the plans such that 95% of the planning target volume (PTV) received at least the prescribed dose. Using 4DCT data set of the patients, multiple 3D plans corresponding to various phases of the respiratory cycle were developed. A 4D dose was derived from the multiple plans by application of a validated non-rigid deformable image registration (DIR) algorithm. The DIR method implemented is primarily based on Thirion's diffusion model also known as the 'demons' algorithm (Thirion 1998, 1999). The demons DIR algorithm was implemented using the National Library of Medicine Insight Toolkit (ITK), an open source cross-platform C++ software toolkit freely available for research purposes (Ibanez et al., 2003). A qualitative validation of the DIR algorithm involved applying the deformation field directly to deform the contours from one phase (a moving CT image set) to the reference phase (the static CT image set) and evaluating the deformed and reference phase contours for matching (see Figures 1 and 2).

We compared the 3D plan versus 4D plan predicted lung V_{20} and mean lung dose (MLD) where V_{20} is defined as the lung volume irradiated by at least 20 Gy. Lung V_{20} and MLD are widely used predictors of radiation pneumonitis (McDonald et al., 1995). We also compared the isocenter point dose (IPD), and the GTV and the PTV generalized equivalent uniform dose (GTV-gEUD and PTV-gEUD). The gEUD is based on the EUD concept, introduced originally as the biologically equivalent dose that, if given uniformly, would lead to the same cell kill as the actual non-uniform dose distribution in the tumor volume and later extended to apply to normal tissues (Niemierko, 1997, 1999). It was calculated as

$$gEUD \quad \left(\frac{1}{N} \sum_{i\ 1}^{N} (D_i)^a \right)^{1/a} \qquad (1)$$

Where Di is the dose in the i^{th} voxel, N is the number of voxels in the anatomic structure of interest, and a is the dose-volume effect parameter specific to the structure of interest. The gEUD for the targets were calculated using a = −10 representative of tumors.

Four delivery techniques were considered; conformal radiotherapy (where no additional margins are used to account for motion – hitherto referred to as 3DCRT), 3D conformal radiotherapy (with 4DCT derived margins to account for motion – hitherto referred to as 4D Static), gated delivery with 30% duty cycle and tracking radiotherapy.

Results:

(a) Qualitative validation of the DIR method

Figure 1 shows a reference image in three planes with superimposed deformation fields. The deformation field is a set of vectors defined per voxel that point from the location in the reference image to their final destination in the moving image. Observe the lung contour mismatch in Figure 2(a) depicting the moving and reference contour and the matching in Figure 2(b) following deformation of the moving contour to the reference phase thus providing a qualitative validation of the deformation algorithm. Note that it is the same deformation field that is used to deform dose distributions from the moving phase to the reference phase from which a 4D dose is derived, namely the weighted sum of all the deformed dose distributions.

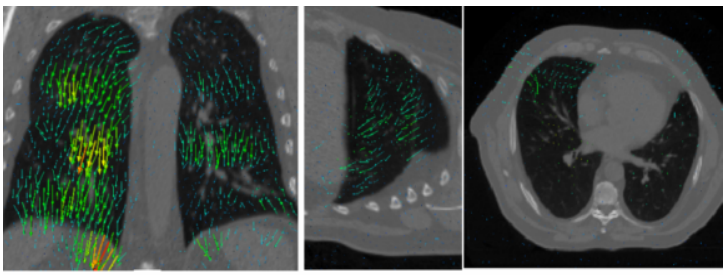

Figure 1: Reference image slices with deformation field superimposed (a) coronal plane (b) saggital plane (c) axial plane

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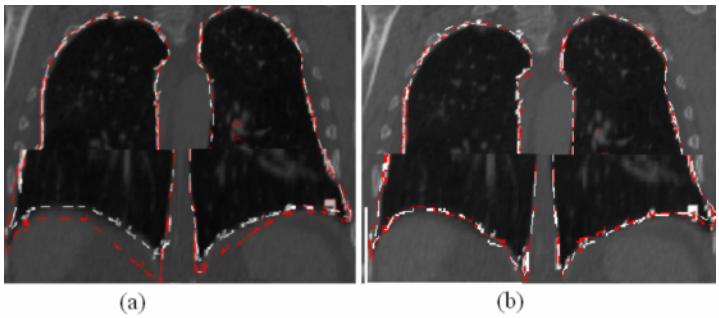

Figure 2: (a) Moving contour (90% phase) and reference contour (40% phase) plotted on reference image. (b) Deformed contour and reference contour plotted on reference image. Note that some regions of the image have been magnified for emphasis.

(b) 3D versus 4D planning

The observed average discrepancies between the 3D and 4D plans predictions were: 17%, 4%, 1%, 1% for lung V_{20}; 8%, 7%, 2%, 2% for the PTV-gEUD; 1%, 4%, 0.6%, 2% for MLD; 0.6%, 2%, 0.8%, 0.4% for the GTV-gEUD and 0.2%, 0.7%, 0.3%, 0.7% for the IPD for the delivery techniques 3DCRT, tracking, 4D static and gating respectively. In other words this should be interpreted as 17% discrepancy in lung V_{20} between the 4D and 3D plans for the 3DCRT delivery, a 4% discrepancy in lung V_{20} between the 4D and 3D plans for the tracking delivery, etc. The 4D DVH and 3D DVH are plotted for one of the patients illustrating the discrepancies for the tracking (Figure 3(a)) and gated deliveries (Figure 3(b)).

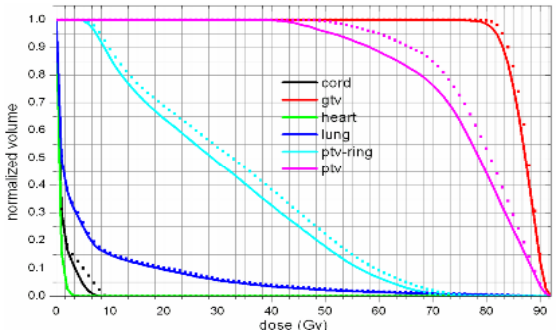

Figure 3 (a) 4D DVH (bold) and 3D DVH (dotted) for Tracking

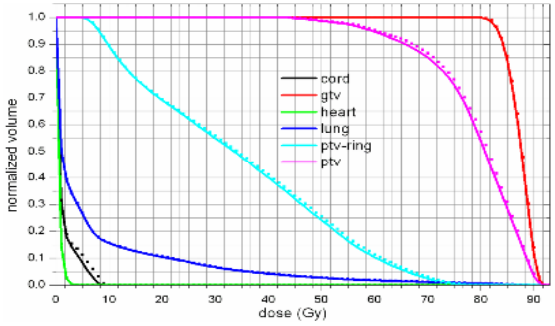

Figure 3 (b) 4D DVH (bold) and 3D DVH (dotted) for Gating

Conclusion:

We observed some trend in the dosimetric parameters considered, for example, the discrepancies between the 4D versus 3D plan predicted parameters for the 4D static and gating techniques were within 2%. Therefore for the patients studied, 3D image based plans may be as effective as 4D plans in predicting the delivered dose distribution for gated and 4D static deliveries involving mobile tumors. The discrepancy for the 3DCRT and tracking techniques were higher. More patient studies with varied tumor characteristics and other dosimetric parameters are required to establish any concrete conclusions.

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