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Assessments and Analytical Predictions of Lung Tumor Motion Based on 4DCT scans

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INTRODUCTION

A great interest in early diagnosis and treatment of pulmonary diseases is to obtain detailed pathological and physiological information non-invasively from dynamically volumetric medical imaging (4DMI). Although lung distensibility (compliance) and regional ventilation-perfusion ratio vary significantly with lung diseases, the knowledge of breathing mechanics has not been sufficient for image-based diagnosis particularly for patients with Chronic Obstructive Pulmonary Disease (CORP).

As a side project of modeling respiratory motions to quantify the lung distensibility and predict local ventilation and perfusion by using 4DMI, we have recently studied the correlation between the nodule/mass displacement and the diaphragm displacement during the 4D CT simulation or 4D CBCT scans of some patients who underwent SBRT or conventional fractionated radiotherapy of none-small-cell lung cancer or lung oligo-metastases. The question we all have in clinical situations is how to precisely target the tumor with minimal acceptable margins during the planning with consideration of the daily setup and treatment variations.

AIM

1. To determine the accuracy and precision in determination of the target motion from standard 4D CT simulations of patients using a commercial deformable image registration (DIR)
2. To find a potential correlation of the internal nodular motion and the diaphragm motion that can be directly measured with daily 4D CBCT or real-time monitoring through marker or optical surface imaging

METHOD

- We used a GE Discovery CT590 RT scanner via 16-row data acquisition combined with a Varian's RPM system for surface surrogated breathing 4DCT scans in cine mode. Elekta X-ray volumetric imaging (XVI) systems on 3 Linear accelerators have been used for 4DCBCT scans that were surrogated with the diaphragm motion.
- Twenty patients with lung GTVs from 0.5 to 111 cc were accrued. As shown in Fig. 1 in the right, each GTVo (in pink) was defined at the first phase of 4D CT scans. Which is then transferred to other phases of 4DCT scans (in yellow) based on manual local DIR by using commercial Velocity AI. The manual registration includes steps of (1) setting all image sets in the same Lung window and level, (2) limiting DIR box to the target, (3) deforming image by applying the ROI continuity constraints and contrast on, (4) transfer GTVo to new phase with DIR and then turn DIR off and transfer GTV in the new phase back to the first phase . We define GTV relative locations of rZ, rY and rX as the ratios of (the stable reference surface to GTV center)/lung dimensions at the level of GTV with the direction of Z from apex to diaphragm, Y from posterior CW to anterior CW, and X from mediastinum to lateral CW, respectively.
- GTV displacements were then linearly regressed with individual variables. Daily 4D CBCTs were acquired for checking GTV motion and prediction.

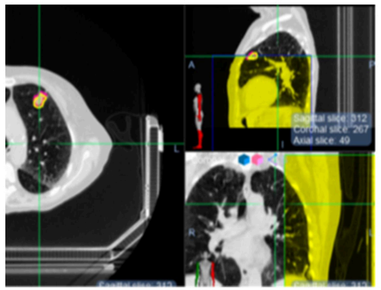

Fig. 1 GTVo (in pink color) defined at the first phase is locally DIR to the nodule in another phase of 4D CT. Three orthogonal cutting thought the lung (green lines) allow us to measure dimensions of the Lung at the GTV level. GTV relative locations to the stable Apex, mediastinum and posterior chest wall (CW) are measured and recorded

RESULTS

GTVs ranged from 0.5 to 111 cc, ipsilateral lung volumes ranged from 1200 to 3000 cc. Measured GTV movements in the lateral, anterior, and longitudinal directions are 0.3 to 9 mm, 1 to 5 mm, and 0.3 to 17 mm, respectively. Measured diaphragm displacements (DD) are 1 to 24 mm with the same average of 13 mm for abdominal compression (less DD in anterior portion) and for the group of patients without abdominal compression. GTV lateral motion is small (< 3 mm except for a GTV at the posterior chest wall with a 9 mm lateral and 8 mm longitudinal movement).

The amplitudes of GTV longitudinal displacements are fairly predicted by y = 0.8712x – 0.05 with R^2 = 0.65 as shown in Fig. 2 without excluding any outliers. GTV trajectories were consistent with daily CBCT scans (not shown here).

Fig. 3 is the results of our early feasibility test on a lung cancer patient for synchronization of surface marker, optical surface (PCA algorithm), and diaphragm during 4D CBCT scanning.

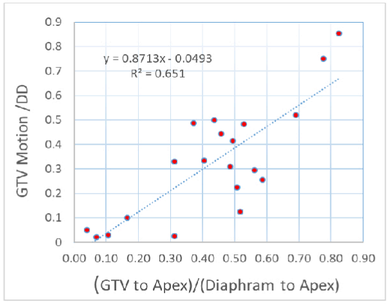

Fig. 2 Plot of relative longitudinal displacement vs the relative location of the GTV on all of the twenty tested cases. If some of GTVs in mediastinum and case with uneven diaphragm motion were excluded, the regression R-square could be increased to ~ 0.9. DIR precision < 1 mm has reached the limit of routine 4D CT

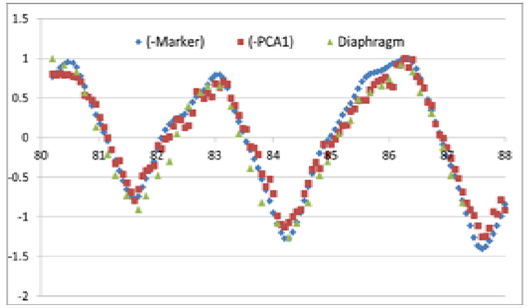

Fig. 3 Results of a measurement for a patient with lung cancer showing clear synchronization between the surface maker, 4D optical surface image, and diaphragm longitudinal motions. This test combined with internal nodule/ Mass motion validation would allow us to make surface guided RT or SBRT in the future

CONCLUSIONS

1. We have observed complicated Lung GTV motions due to variations of anatomic and other patient conditions but mostly measurable with an updated commercial DIR systems
2. Our measurement uncertainty is ~3 mm mainly due to the thicker slice thickness of 2.5 mm in our 4D CT scans from the limit of CT scanner to scan the entire lung. The DIR system can determine small nodule motion of 0.2 mm.
3. A linear correlation of relative longitudinal displacements to the relative locations of the GTV to the stable reference surfaces might be useful in future real-time image-guided SBRT or radiotherapy.

REFERENCES

N/A

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