



Respiration Motion Assessment of Liver Tumor Using 4D Cone-beam Computer Tomography Technique

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Motivation

Ren *et. al.* have proposed a novel CBCT estimation method by deforming planning CT images img [1].

It has been showed that the method has better performance than standard FDK method in terms of detecting inter-fraction organ motion and volume changes, when the scan angle is limited and the number of X-ray projections is low[2].

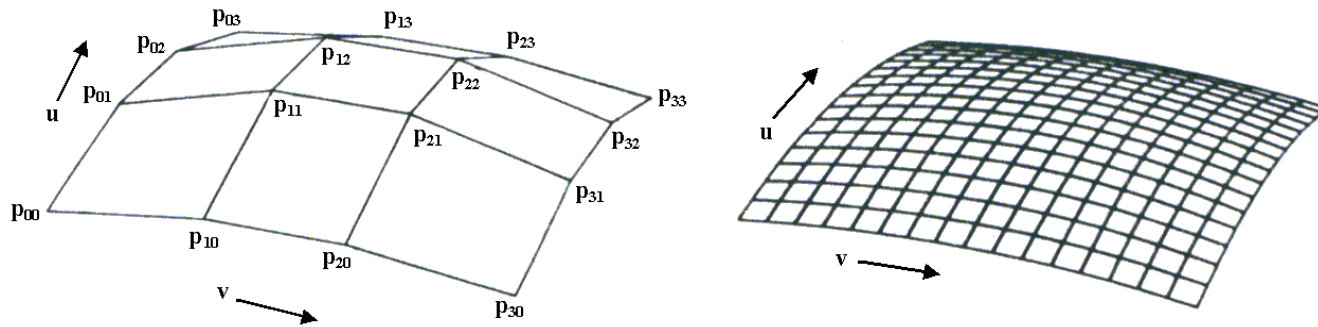
In this study, we extend Ren's method to 4D free-breathing CBCT scans and use it to detect three-dimensional tumor motion.

Method

- In this study, breath-hold(BH) CBCT scan and free-breath (FB)-CBCT scan were acquired in the same position.
- Prior information: BH-CBCT image set $I^{\text{BH}}(x,y,z)$ reconstructed using FDK algorithm.
- Deformation to be solved: BH-CBCT \Rightarrow FB-CBCT
- Use deformation map $V^t(x,y,z)$ to represent organ and tumor motion at frame t during free-breath(FB) CBCT scan.
- FB-CBCT image at frame t was estimated by the deformed BH-CBCT images $I^{\text{BH}}(x+V_x^t, y+ V_y^t, z+V_z^t)$

B-spline based deformation

- To ensure smooth deformation, the deformation map $V^t(x,y,z)$ was characterized by a set of deformation vectors $U^t(u,v,w)$ at equally-spaced grid points.



- The deformation map off the grid points was calculated based on cubic B-spline interpolation.

- We chose B-spline interpolations instead of adding extra constraints such as bending energy as in [1][2],

$$E \Rightarrow \iiint \left(\left(\frac{\partial^2 V}{\partial x^2} \right)^2 + \left(\frac{\partial^2 V}{\partial y^2} \right)^2 + \left(\frac{\partial^2 V}{\partial z^2} \right)^2 + 2 \left(\frac{\partial^2 V}{\partial x \partial y} \right)^2 + 2 \left(\frac{\partial^2 V}{\partial y \partial z} \right)^2 + 2 \left(\frac{\partial^2 V}{\partial x \partial z} \right)^2 \right) dx dy dz$$

- The strength of extra constraints depends on image quality and need to be optimized through simulations.
- By using B-spline method, we can intuitively choose grid size based on anatomy and the setting is independent of imaging quality.

Currently, 4D imaging is available for simulation & planning,
but not for patient setup & treatment



Cone beam (CB) CT Scan for setup

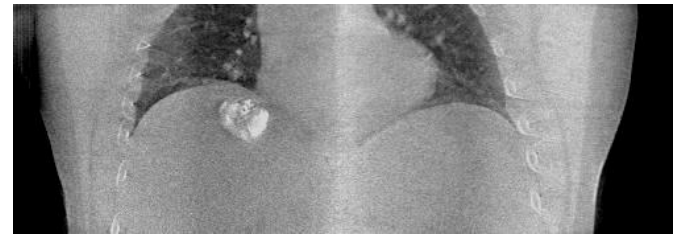
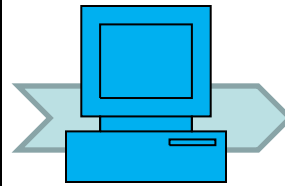
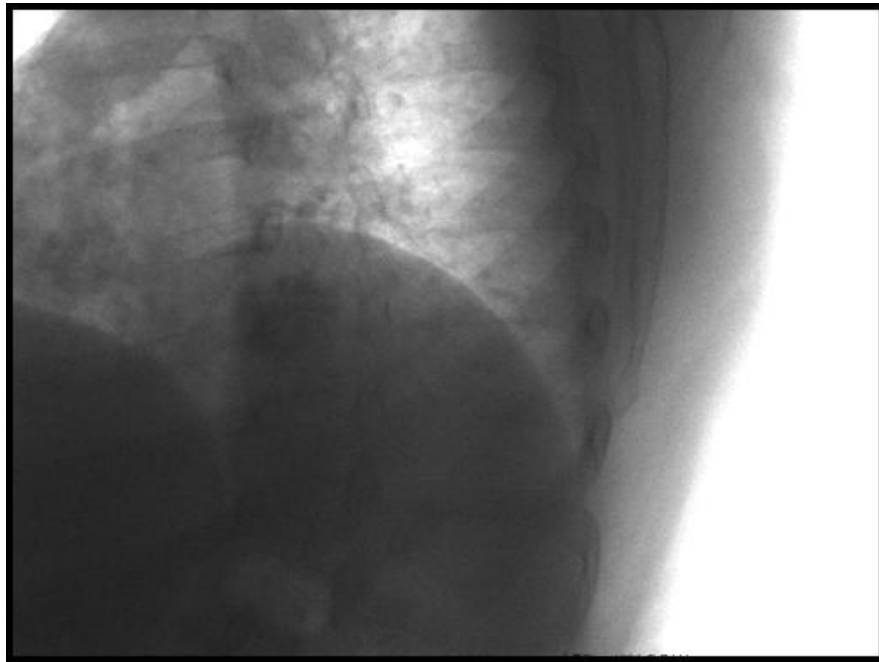


CT Scan for simulation

Breath-hold during CBCT acquisition



No respiration movement



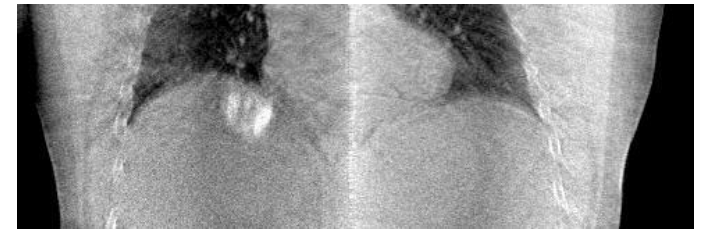
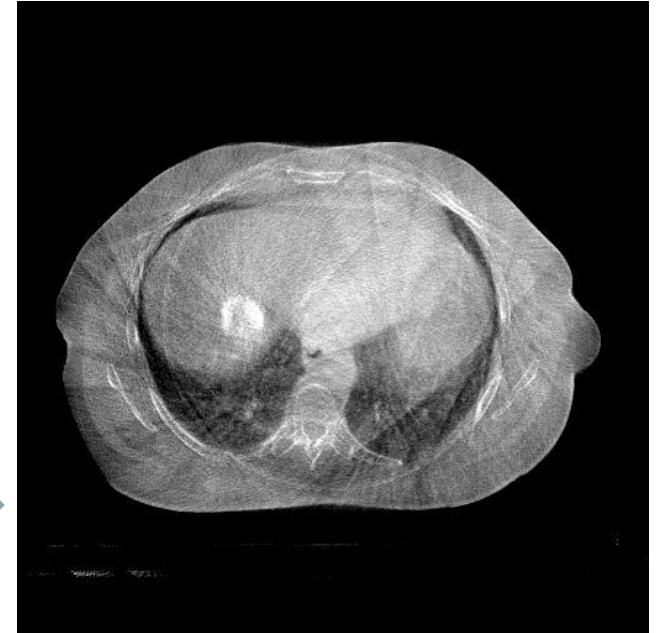
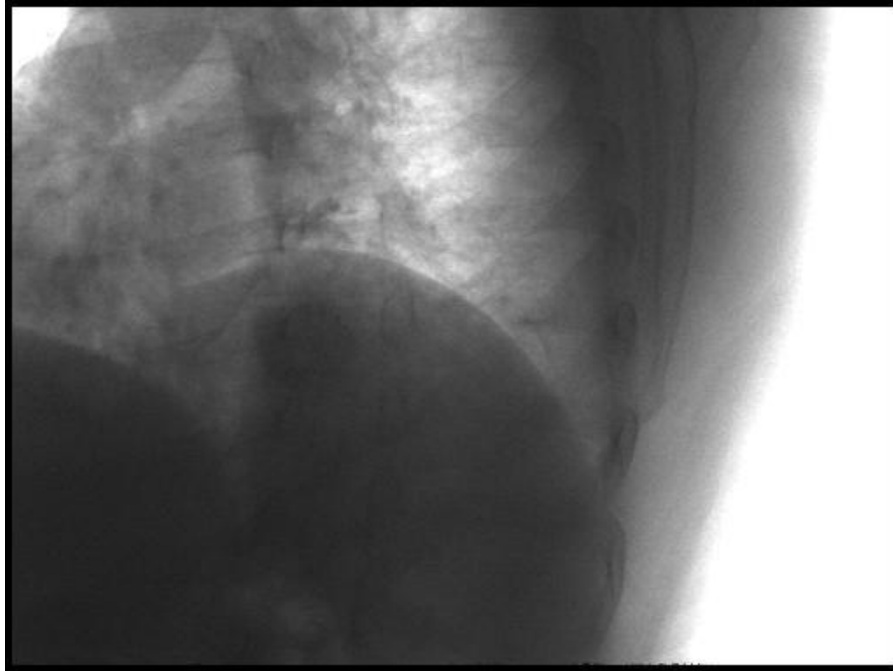
3D anatomy can be reconstructed based on the projection sequence (>300 projections).

Not all patients can hold his/her breath. Even for those who can, the 60 second CBCT scan need to be split in 2-3 sessions.

Free-breathing during CBCT acquisition

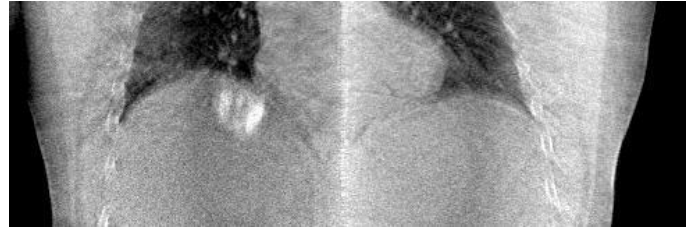
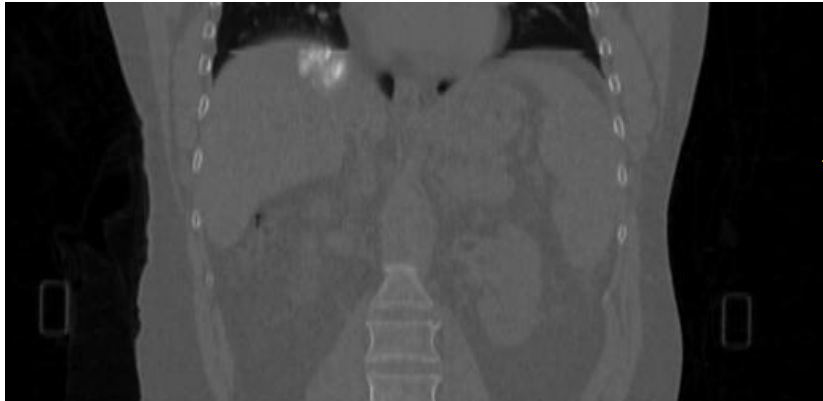


1-2 cm superior-inferior movement



Free-breathing CBCT is applicable to all patients. However, standard 3D CT reconstruction algorithm can not resolve the motion. New 4D reconstruction method is needed.

Currently, 4D imaging is available for simulation & planning, but not for patient setup & treatment

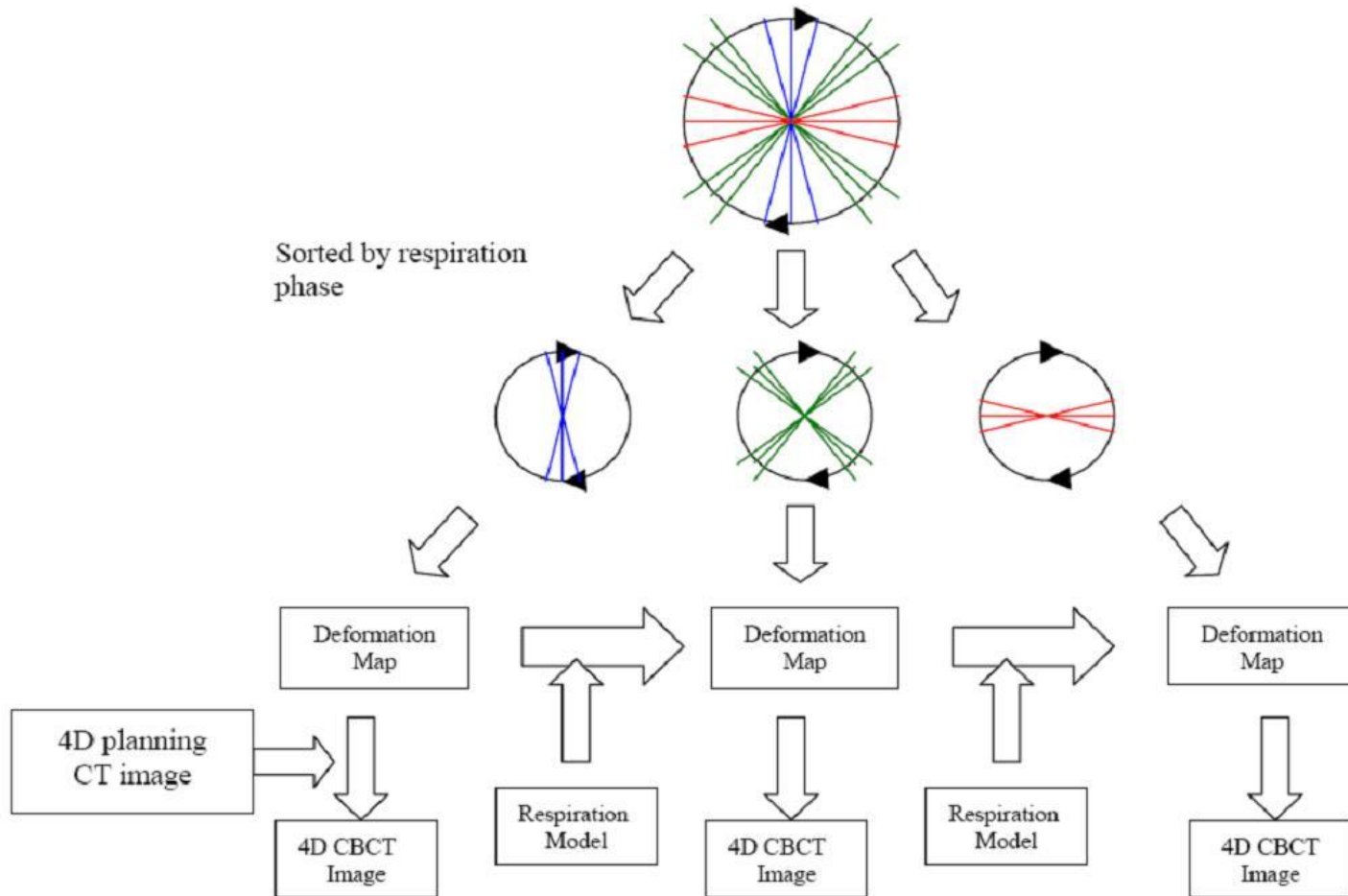


CT Scan for simulation

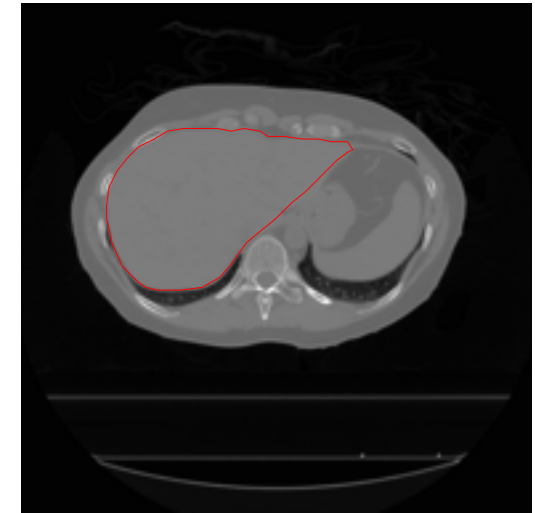
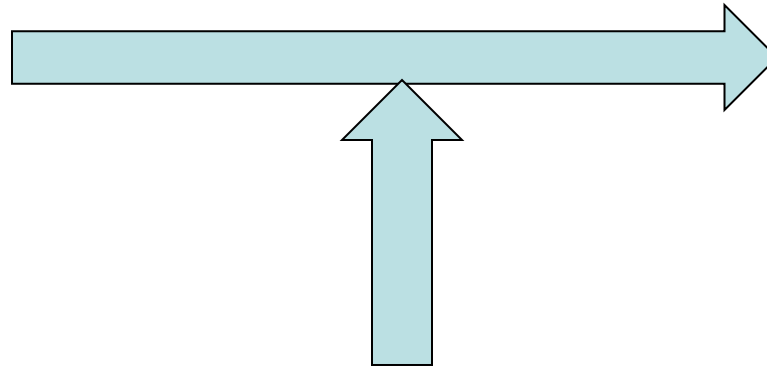
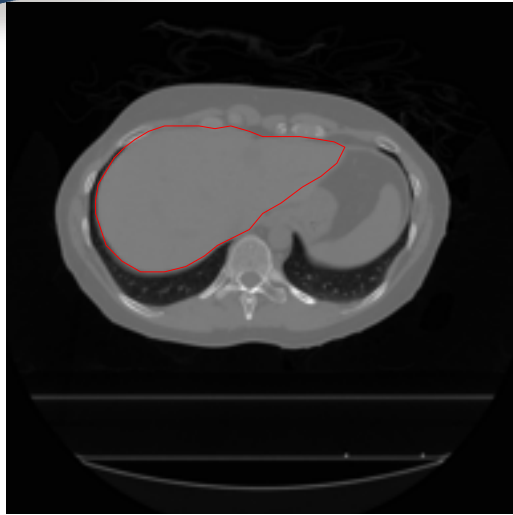


Cone beam (CB) CT Scan for setup

Reconstruction Scheme

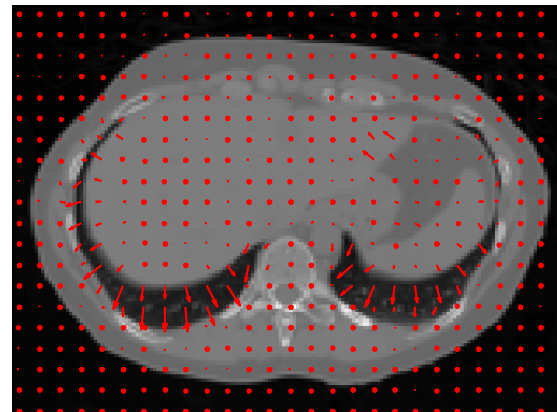


New strategy: Reconstruct CBCT using deformation field



CBCT

**Prior image:
e.g. Planning CT**

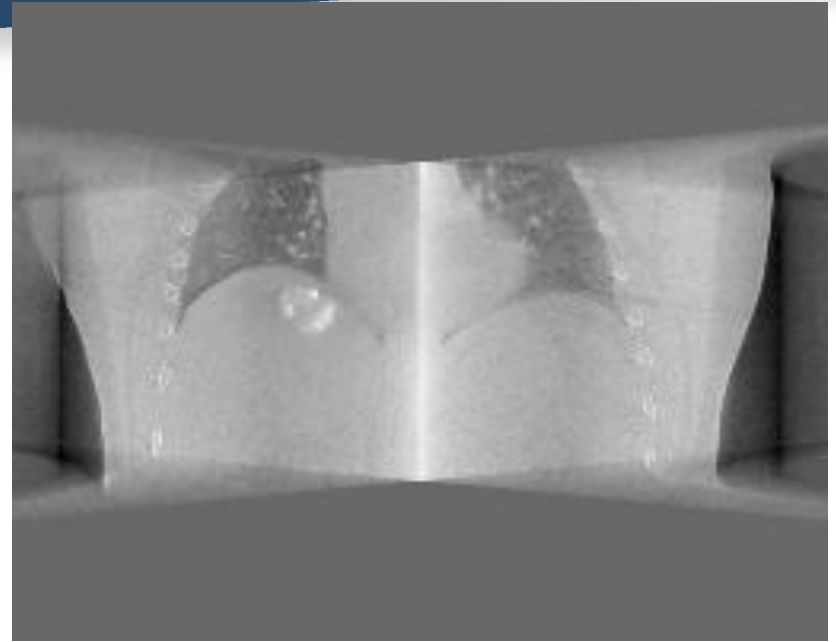


Solved deformation field

Result



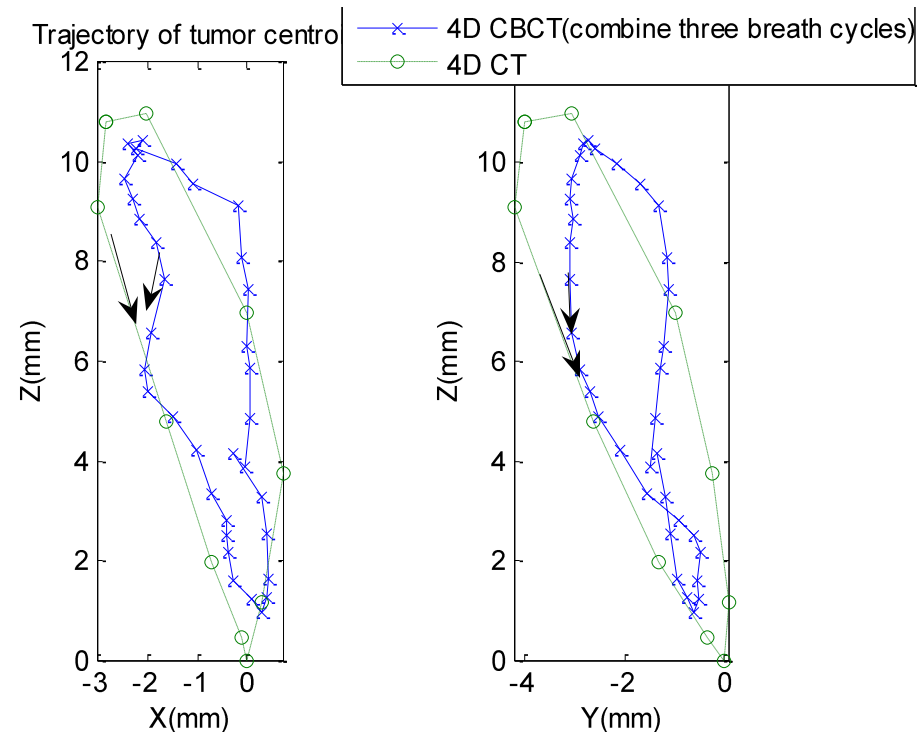
4D CT acquired in simulation



4D CBCT reconstructed from projections

Compare tumor trajectory in 4D CT and 4D CBCT

- Using 4D CBCT, the tumor was detected to have 9.5 mm movement along the sup/inf direction. Compared with the 4D CT value 11.0mm, the error was 1.5 mm or 14%.
- **Conclusion:** The pivot study showed that the proposed method can detect the movement of live tumor.



Acknowledgements

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Reference

- [1] L. Ren, J. Zhang, D. Thongphiew, D. J. Godfrey, Q. J. Wu, S. Zhou, and F. Yin, “A novel digital tomosynthesis (DTS) reconstruction method using a deformation field map”, *Medical Physics*, Vol 35, Issue 7, July 2008, pp. 3110-3115.
- [2] Lei Ren., Indrin J. Chetty, Junan Zhang, Jian-Yue Jin, Q. Jackie Wu, Hui Yan, David M. Brizel, W. Robert Lee, Christopher G. Willett, Benjamin Movsas, Fang-Fang Yin, Ph.D. “Optimization and Clinical Evaluation of a 3D Cone-Beam CT (CBCT) Estimation Method Using a Deformation Field Map”, *Int J Radiat Oncol Biol Phys.* 2010,