TomoTherapy Related Projects

- An image guidance alternative on Tomo
- Low dose MVCT reconstruction
- Patient Quality Assurance using Sinogram

Development of A Novel Image Guidance Alternative for Patient Localization using Topographic Images for TomoTherapy

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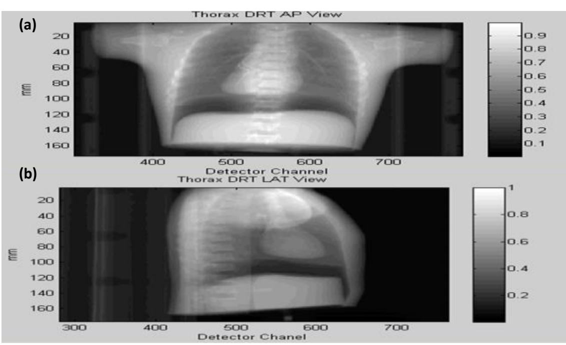
OBJECTIVES

The unique geometric design and integrated on-board imaging system allows for acquisition of topographic images on Tomotherapy Hi·ART system. The objective is to develop a faster and lower dose topogram based image registration for TomoTherapy as an alternative image guidance tool to volumetric MVCT.

METHODS

Topogram procedures were created and performed for three anthropomorphic phantoms, including head (20 cm length), thorax (45 cm length) and spine (17 cm length) phantoms. The topogram procedures consisted of four couch speeds, 1 cm/s, 2 cm/s, 3 cm/s, and 3.99 cm/s (maximum couch speed) with a scanning duration of 30 seconds. All MLC leaves were opened to provide the largest field of view. A data compression factor of 1 was used for the topographic scans. An air scan was acquired to normalize the raw detector output. For patient localization, two topograms were acquired for each phantom and four different couch speeds at gantry angles of 0° and 90°. To obtain the correct reference image from the simulation CT, a digitally reconstructed topogram (DRT, **Figure 1**) was generated in the TomoTherapy beam and detector geometry. To assess daily setup errors, known shifts were applied to the phantom for the topographic images (**Figure 2**). Image registration was performed by rigidly aligning the visible anatomy of the phantom in the topogram with the anatomy of the created DRT (**Figure 3**). MVCT scans were performed for the same phantoms using the normal imaging jaw width (4 mm). For MVCT imaging registration, we used bony and soft tissue to align the MVCT to the kVCT. The MVCT was set up with known shifts from the kVCT position. The shifts derived from topogram were compared to the MVCT image.

Figure 1: Digitally Reconstructed Topogram (the reference image) generated from the CT simulation in the TomoTherapy beam and detector geometry for a thorax phantom. **(a)** anteroposterior MV topogram and **(b)** left lateral MV topogram.



CONCLUSION

Topograms with proper couch speed (<3 cm/s) provide reliable patient localization while significantly reducing pre-treatment imaging time as well as imaging doses. Topogram can be used as an alternative and/or additional patient alignment tool to MVCT on TomoTherapy.

RESULTS

MVCT yielded positional offsets of 2 mm in the medio-lateral (ML), cranial-caudal (CC), and anterior-posterior (AP) directions. For the thorax phantom, the relative positional errors observed in all topograms (with different couch speeds) were 1.5 mm in the ML, 8.1 mm in the CC, and 2.5 mm in the AP direction. Between couch speeds of 1 cm/s, 2 cm/s and 3 cm/s, the relative shifts were within 3 mm in all ML and AP directions, and 5 mm in CC direction; while for fast couch speed such as 4.0 cm/s, larger relative shifts in CC direction between different couch speeds was seen (**Table 1**).

At maximum couch speed, the topogram was markedly blurred in the CC direction. However, the blurred voxels resulted in a high positional error of 8.1 mm in the CC direction. The errors in the ML and AP directions were on the order of the slice thickness of the MVCT, which are at clinical acceptable level. Based on our preliminary measurements, a couch speed of 3 cm/s might be the fastest couch speed achievable with reasonable positional errors due to voxel deformation in the topogram.

Compared with the imaging acquisition time of 3-5 min for MVCT scans, the time required to acquire clinically acceptable topograms for the selected phantom were significantly longer using topograms. Based on these results, a couch speed of 3 cm/s is the fasted couch speed achievable with reasonable positional errors due to voxel deformation in the topogram.

Figure 2: Reconstructed MV TomoTherapy Topograms at couch speeds of 1 and 4 cm/s generated in the TomoTherapy beam and detector geometry. (a) and (b)couch speed of 1 cm/s; (c) and (d) couch speed of 4.0 cm/s.

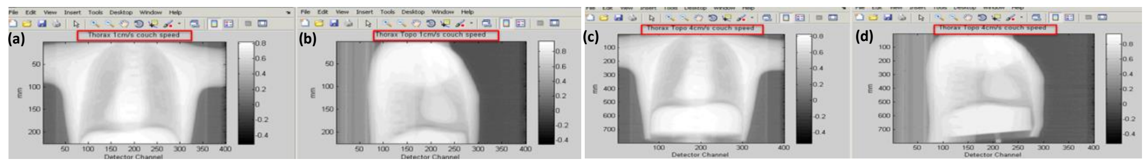
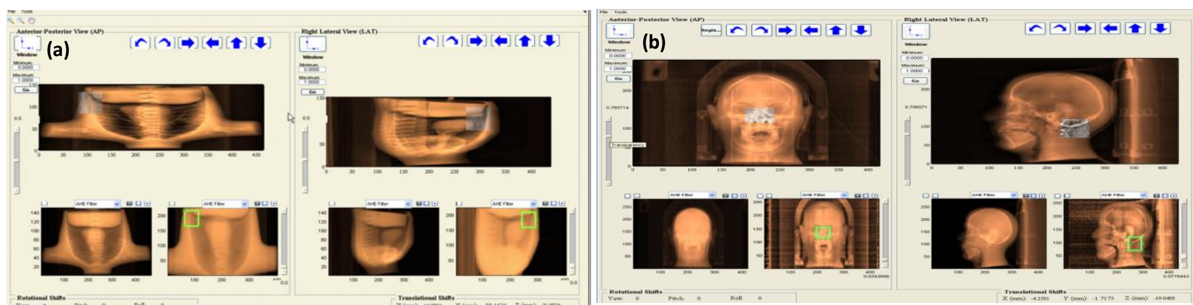


Figure 3: MV topogram based registration by rigid aligning the reconstructed Topogram to the DRT for (a) a thorax phantom and (b) a head phantom.



*(b) Courtesy of Dr. Kevin Moore.

Table 1: Relative positional errors at different couch speeds using MV Topogram registration versus MVCT registration on TomoTherapy.

Direction	MVCT (mm)	Topogram* (mm)
ML	2	1.5
CC	2	8.1
AP	2	2.5

* Relative positional errors for the topograms at different couch speeds.

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3. Keller, H et al., Monte Carlo study of a highly efficient gas ionization detector for megavoltage imaging and image-guided radiotherapy, Med. Phys. 29 (2), 165 (2002).

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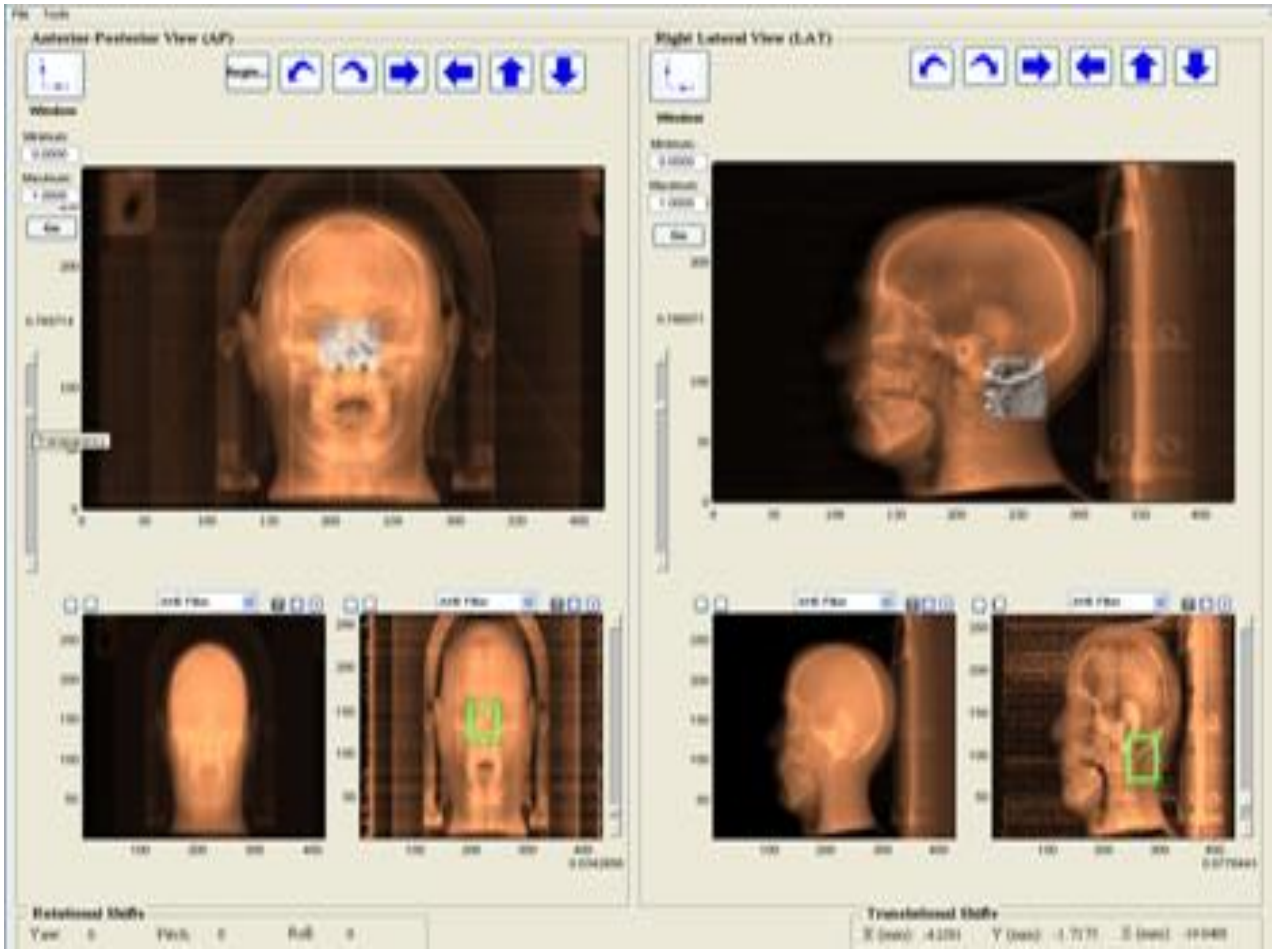
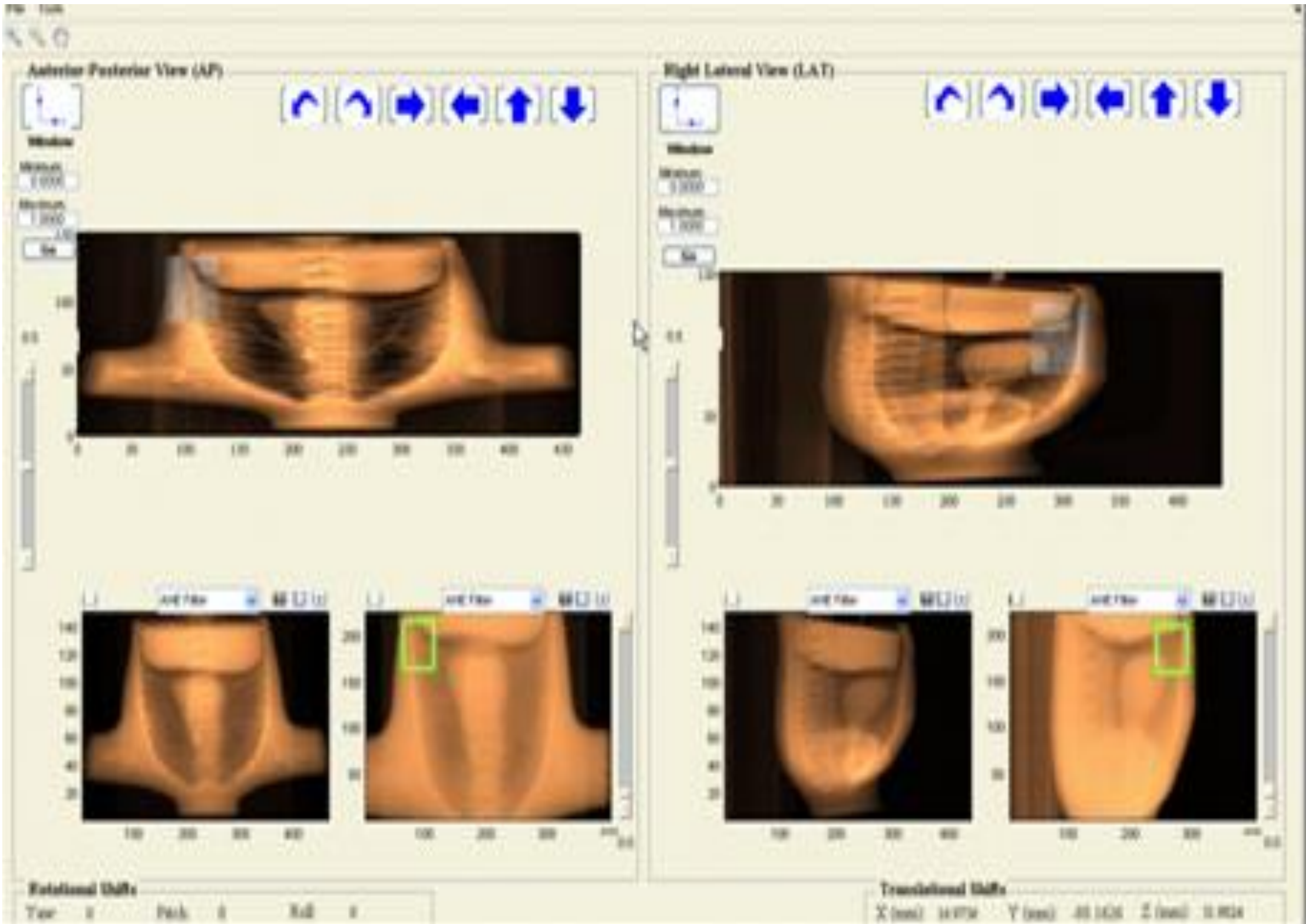

Anterior Posterior View (AP)
Right Lateral View (LAT)
Rotational Shifts
Translational Shifts



Anterior Posterior View (AP)
Right Lateral View (LAT)
Rotational Shifts
Yaw
Pitch
Roll
Translational Shifts
X (mm)
Y (mm)
Z (mm)

ASTRO 2013 Oral

Improved Imaging Quality for Megavoltage CT on TomoTherapy via A Novel Iterative Reconstruction Method based on Tensor Framelet

X. Sharon Qi, Hao Gao, Daniel Low

Purpose: To investigate the feasibility of improving megavoltage CT (MVCT) imaging quality and reducing imaging dose for TomoTherapy using a novel iterative reconstruction technique based on tensor framelet (TF) for better patient alignment.

Methods: Anthropomorphic phantoms and patients were scanned on a TomoTherapy HD unit (Accuray Inc., Sunnyvale, CA). The standard MVCT scanning protocol was used: 1 mm collimator setting (J1), gantry period of 10 seconds at couch speed of 8 mm per rotation. Normal MVCT scan mode (4 mm scanning thickness) was used for all the MVCT scans. The raw CT detector data were exported out for each phantom or patient immediately after each MVCT scan, an immediate subsequent air scan was also acquired and exported to normalize the raw detector output. The MVCT reconstruction was performed under actual TomoTherapy geometry using a novel TF-based reconstruction algorithm. The GPU-based reconstruction algorithm was developed and implemented with a NVIDIA GeForce GTX 680 GPU card. The proposed TF-based reconstruction was compared with the filtered backprojection (FBP) using a H&N and a pelvis phantom, and a H&N and a prostate patient. The image was reconstructed and

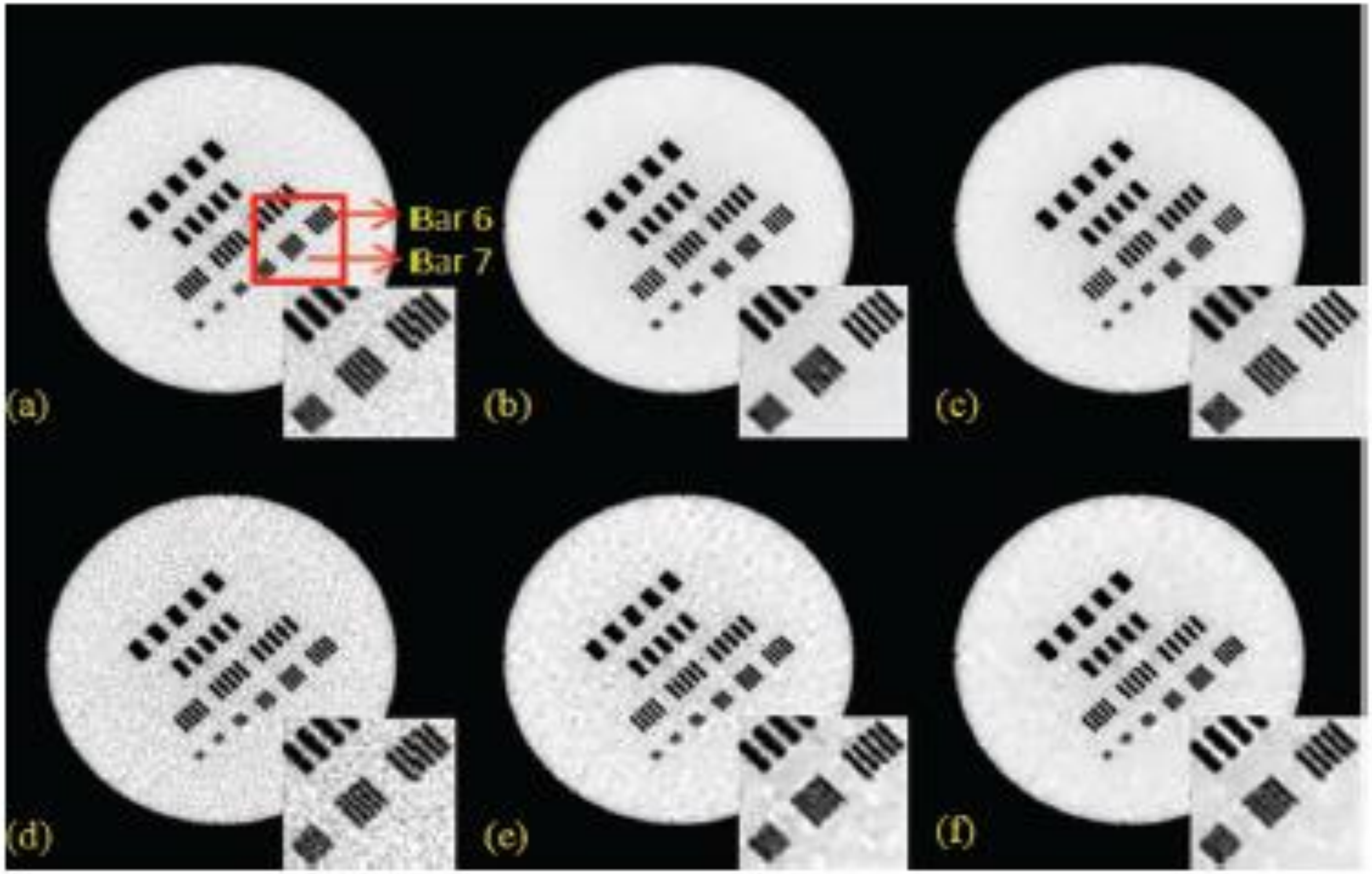


FIG. 2. Resolution slice reconstruction results from the Siemens image quality phantom. (a), (b), and (c) are from FBP, TV, TF with 100% data; (d), (e), and (f) are from FBP, TV, TF with 25% data. The zoom-in details are shown for the ROI in the selected square.

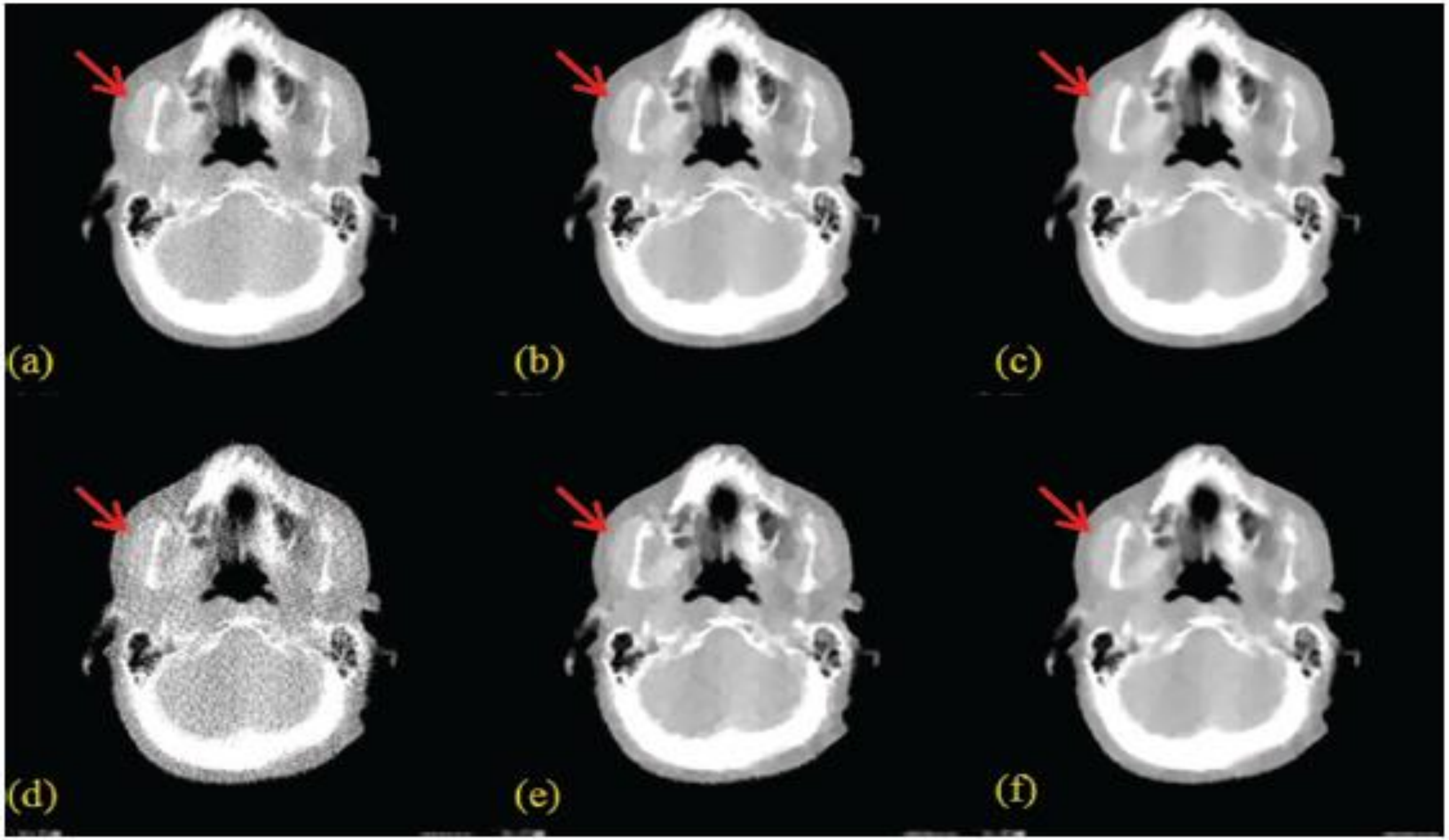


FIG. 4. H&N patient results. (a), (b), and (c) are from FBP, TV, and TF with 100% data; (d), (e), and (f) are from FBP, TV, and TF with 25% data.

Megavoltage CT imaging quality improvement on TomoTherapy via tensor framelet

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Purpose: This work is to investigate the feasibility of improving megavoltage imaging quality for TomoTherapy using a novel reconstruction technique based on tensor framelet, with either full-view or partial-view data.
Methods: The reconstruction problem is formulated as a least-square L1-type optimization problem, with the tensor framelet for the image regularization, which is a generalization of L1, total variation, and wavelet. The high-order derivatives of the image are simultaneously regularized in L1 norm at multilevel along the *x*, *y*, and *z* directions. This convex formulation is efficiently solved using the Split Bregman method. In addition, a GPU-based parallel algorithm was developed to accelerate image reconstruction. The new method was compared with the filtered backprojection and the total variation based method in both phantom and patient studies with full or partial projection views.
Results: The tensor framelet based method improved the image quality from the filtered backprojection and the total variation based method. The new method was robust when only 25% of the projection views were used. It required ~2 min for the GPU-based solver to reconstruct a 40-slice 1 mm-resolution 350 × 350 3D image with 200 projection views per slice and 528 detection pixels

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Clinical Outcome Assessment

- TCP/NTCP
- Clinical dose-response assessment
- Outcome prediction

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doi:10.1016/j.ijrobp.2005.12.022

PHYSICS CONTRIBUTION

AN ESTIMATION OF RADIOBIOLOGIC PARAMETERS FROM CLINICAL OUTCOMES FOR RADIATION TREATMENT PLANNING OF BRAIN TUMOR

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Purpose: To estimate a plausible set of radiobiologic parameters such as α, α/β values, from clinical outcomes for biologically based radiation treatment planning of brain tumors.
Methods and Materials: Linear-quadratic (LQ) formalism and the concept of equivalent uniform dose were used to analyze a series of published clinical data for malignant gliomas involving different forms of radiation therapy.
Results: A plausible set of LQ parameters was obtained for gliomas: $\alpha = 0.06 \pm 0.05\ Gy^{-1}$, $\alpha/\beta = 10.0 \pm 15.1$ Gy, the tumor cell doubling time $T_d = 50 \pm 30$ days, with the repair half-time of 0.5 h. The present estimated biologic parameters can reasonably predict the effectiveness of most of the recently reported clinical results employing either single or combined radiation therapy modalities. Different LQ parameters between Grade 3 and Grade 4 astrocytomas were found, implying the radiosensitivity for different grade tumors may be different. Smaller α, β from *in vivo* was observed, indicating lower radiosensitivity occurred *in vivo* as compared with *in vitro*.
Conclusions: A plausible set of radiobiologic parameters for gliomas was estimated based on clinical data. These parameters can reasonably predict most of the clinical results. They may be used to design new treatment fractionation schemes and to evaluate and optimize treatment plans.

Malignant gliomas, Glioblastoma multiforme, Linear-quadratic model, Equivalent uniform dose.

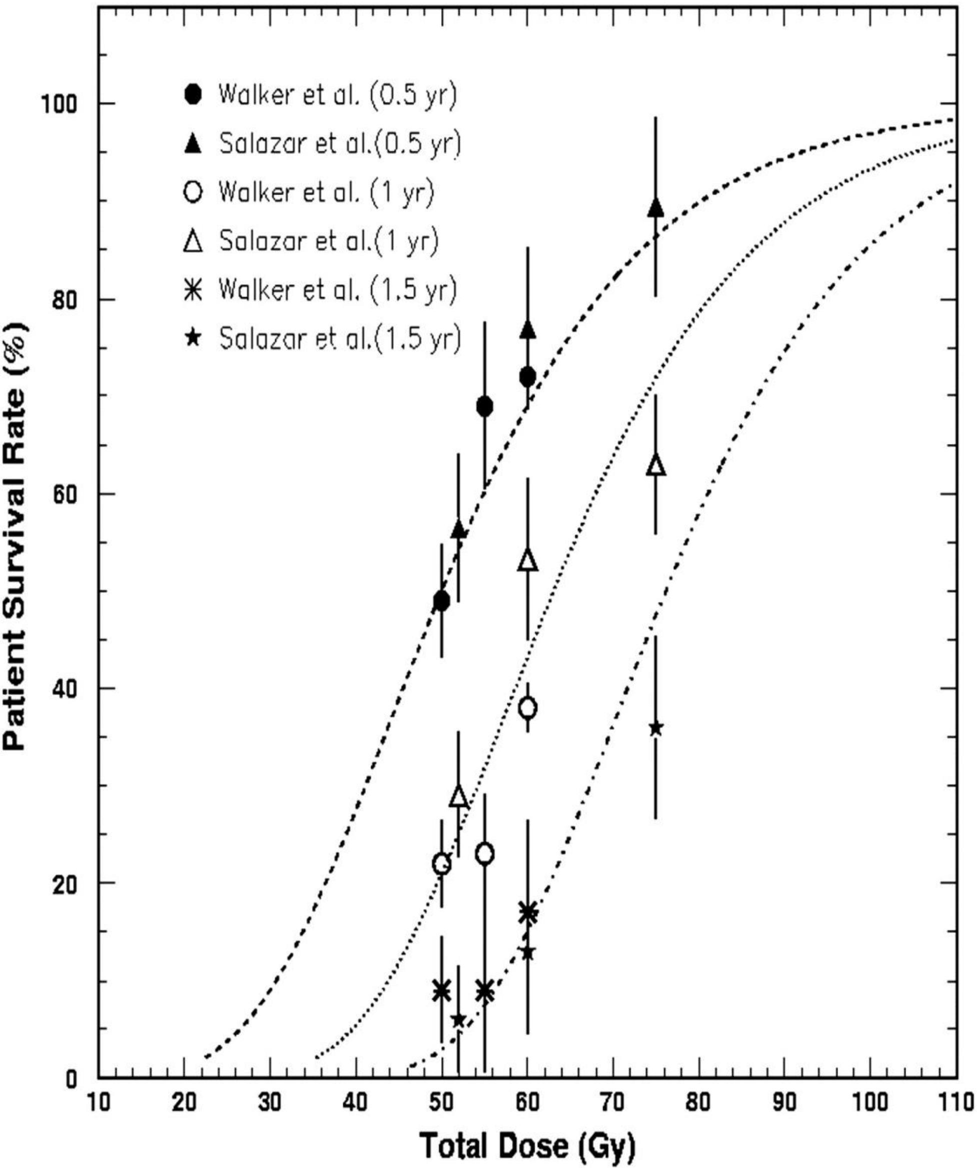

Fig. 2. Dose–response curves for malignant gliomas at 0.5, 1.0, and 1.5 years. The patient survival rates given by Walker et al. (9) and Salazar et al. (10 and 11) are considered. The lines represent the fitting to the data points for the survival rates given at 0.5, 1.0, and 1.5 years, respectively. The fitting yields: α = 0.06 ± 0.05 Gy−1 and α/β = 10.0 ± 15.1 Gy. The error bars represent statistical uncertainty.

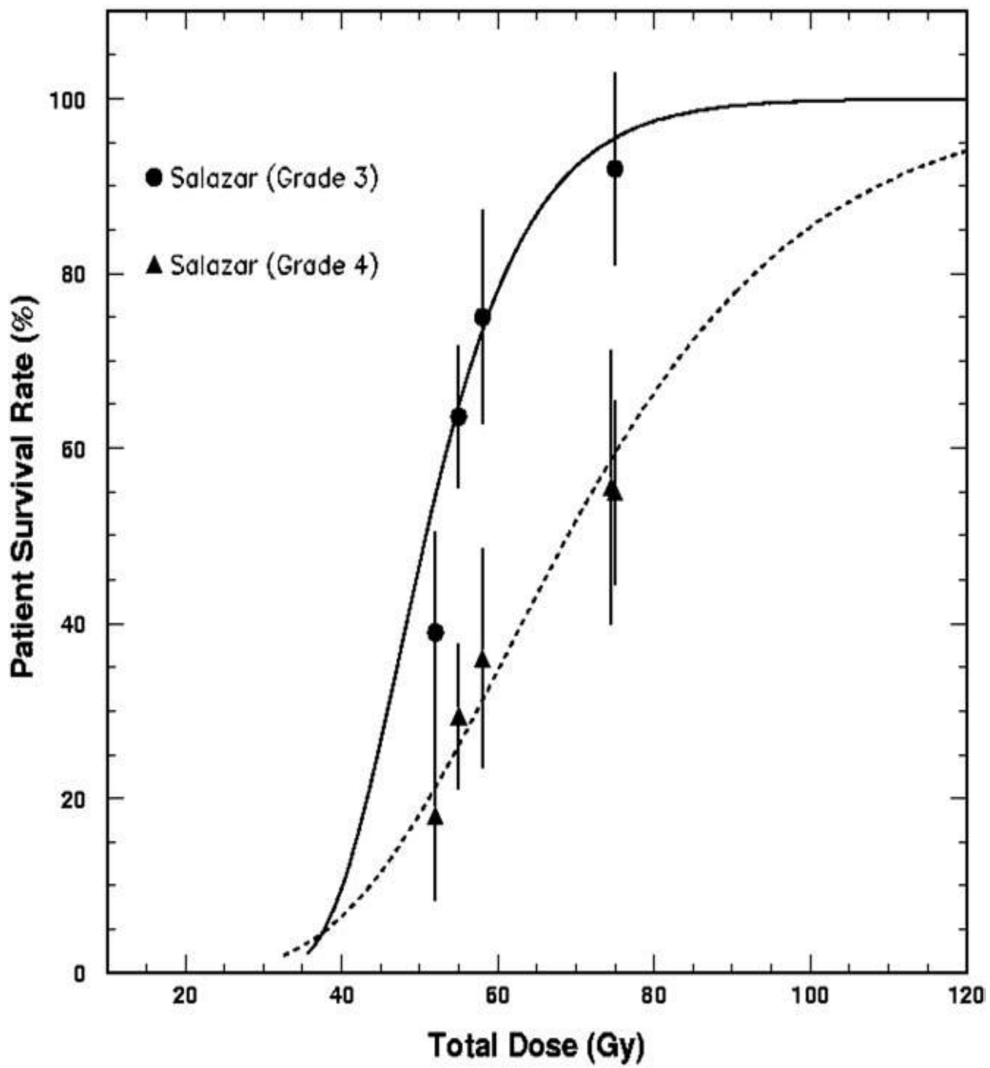

Fig. 5. Fitting of different grades of astrocytomas using the data of Salazar et al. (10 and 11). For Grade 3 astrocytoma, our fitting yields: $\alpha = 0.11 \pm 0.10\ Gy^{-1}$ and $\alpha/\beta = 5.8 \pm 11.8$ Gy; whereas, for Grade 4 astrocytoma, $\alpha = 0.04 \pm 0.06\ Gy^{-1}$ and $\alpha/\beta = 5.6 \pm 9.4$ Gy.

Int. J. Radiation Oncology Biol. Phys., Vol. 64, No. 5, pp. 1570–1580, 2006

Data Mining

- Data analysis
- Time series analysis

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Physics Contribution

Assessment of Interfraction Patient Setup for Head-and-Neck Cancer Intensity Modulated Radiation Therapy Using Multiple Computed Tomography-Based Image Guidance

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Summary

Image guidance systems are commonly used with intensity modulated radiation therapy (IMRT) in head-and-neck cancer irradiation. We retrospectively analyzed 3302 interfraction computed tomography (CT) images for 117 patients using multiple image guidance modalities: kilovoltage cone-beam CT (KVCBCT), megavoltage fan-beam CT (MVFBCT), and megavoltage cone-beam CT (MVCBCT). Our data suggest that the clinical target volume-to-planned

Purpose: Various image guidance systems are commonly used in conjunction with intensity modulated radiation therapy (IMRT) in head-and-neck cancer irradiation. The purpose of this study was to assess interfraction patient setup variations for 3 computed tomography (CT)-based on-board image guided radiation therapy (IGRT) modalities.

Methods and Materials: A total of 3302 CT scans for 117 patients, including 53 patients receiving megavoltage cone-beam CT (MVCBCT), 29 receiving kilovoltage cone-beam CT (KVCBCT), and 35 receiving megavoltage fan-beam CT (MVFBCT), were retrospectively analyzed. The daily variations in the mediolateral (ML), craniocaudal (CC), and anteroposterior (AP) dimensions were measured. The clinical target volume-to-planned target volume (CTV-to-PTV) margins were calculated using $2.5\Sigma + 0.7\,\sigma$, where Σ and σ were systematic and random positioning errors, respectively. Various patient characteristics for the MVCBCT group, including weight, weight loss, tumor location, and initial body mass index, were analyzed to determine their possible correlation with daily patient setup.

Results: The average interfraction displacements (± standard deviation) in the ML, CC, and AP directions were 0.5 ± 1.5, −0.3 ± 2.0, and 0.3 ± 1.7 mm (KVCBCT); 0.2 ± 1.9, −0.2 ± 2.4, and 0.0 ± 1.7 mm (MVFBCT); and 0.0 ± 1.8, 0.5 ± 1.7, and 0.8 ± 3.0 mm (MVCBCT). The day-to-day random errors for KVCBCT, MVFBCT, and MVCBCT were 1.4-1.6, 1.7, and 2.0-2.1 mm. The interobserver variations were 0.8, 1.1, and 0.7 mm (MVCBCT); 0.5, 0.4, and 0.8 mm (MVFBCT); and 0.5, 0.4, and 0.6 mm (KVCBCT) in the ML, CC, and AP directions, respectively. The maximal calculated uniform CTV to PTV margins were 5.6, 6.9, and 8.9 mm

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Analysis of Patient Setup Errors and Autocorrelation for Head-and-neck Radiotherapy Using Volumetric Computed Tomography

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