

# An automatic dose verification system for adaptive radiotherapy for helical tomotherapy

**Xiaohu Mo, Mingli Chen, Donald Parnell, Gustavo Olivera, Daniel Galmarini and Weiguo Lu**

21<sup>st</sup> Century Oncology, Madison, WI, USA

xmo@rtsx.com

**Abstract.** Purpose: During a typical 5-7 week treatment of external beam radiotherapy, there are potential differences between planned patient's anatomy and positioning, such as patient weight loss, or treatment setup. The discrepancies between planned and delivered doses resulting from these differences could be significant, especially in IMRT where dose distributions tightly conforms to target volumes while avoiding organs-at-risk. We developed an automatic system to monitor delivered dose using daily imaging. Methods: For each treatment, a merged image is generated by registering the daily pre-treatment setup image and planning CT using treatment position information extracted from the Tomotherapy archive. The treatment dose is then computed on this merged image using our in-house convolution-superposition based dose calculator implemented on GPU. The deformation field between merged and planning CT is computed using the Morphon algorithm. The planning structures and treatment doses are subsequently warped for analysis and dose accumulation. All results are saved in DICOM format with private tags and organized in a database. Due to the overwhelming amount of information generated, a customizable tolerance system is used to flag potential treatment errors or significant anatomical changes. A web-based system and a DICOM-RT viewer were developed for reporting and reviewing the results. Results: More than 30 patients were analysed retrospectively. Our in-house dose calculator passed 97% gamma test evaluated with 2% dose difference and 2mm distance-to-agreement compared with Tomotherapy calculated dose, which is considered sufficient for adaptive radiotherapy purposes. Evaluation of the deformable registration through visual inspection showed acceptable and consistent results, except for cases with large or unrealistic deformation. Our automatic flagging system was able to catch significant patient setup errors or anatomical changes. Conclusions: We developed an automatic dose verification system that quantifies treatment doses, and provides necessary information for adaptive planning without impeding clinical workflows.

## 1. Introduction

As modern external beam radiotherapy techniques become more complex and allow for highly conformal treatment plans, accurate verification of the dose delivered to patients is also becoming a necessity. Patients are never treated exactly as planned, which could be due to setup error, anatomical change or machine behavior. Without a comprehensive delivery verification program, these uncertainties in treatment may go undetected. In vivo dosimetric verification is especially important for hypo-fractionated treatments, dose escalation schemes, and stereotactic body radiation therapy, where errors in a single fraction could have a significant dosimetric effect on the treatment outcome.



Therefore, in this work, we present an automatic dosimetric verification system for helical tomotherapy (HT) in order to monitor the aforementioned potential treatment deviations, and provide triggers and guides to clinic workflow such as adaptive planning. The system re-computes treatment doses on daily images and provide cumulative dose during the course of treatments using deformable registration. We anticipate the system will lead to automatic adaptive planning, which greatly facilitate adaptive radiotherapy.

## 2. Methods

The diagram in Figure 1 illustrates the workflow for each patient fraction treated. 1) The input is naturally the planning information, including the treatment plan and CT; as well as daily imaging, machine output etc. In order to recalculate dose on the same image space as the plan CT, a merged image is generated by filling the missing information, both radially and in the superior/inferior direction, of the daily CT (approximately 40 cm field of view) with plan CT as described in Langen et al. [1]. This method assumes anatomy outside of field of view to be the same with plan CT, and users are warned if regions of interest are not imaged. 2) The planned beams are then re-computed on the merged image using our in house dose calculation engine which employs collapsed cone convolution/superposition algorithm [2] and implemented on graphic processors. Note that to allow for correct density mapping, we have also incorporated density calibration in routine quality assurance of imaging devices. 3) The deformation vector field (DVF) between the merged and planning CT is then computed with Morphons algorithm [3], and used to warp the planning contours to the merged image. The analytically computed inverse DVF [4] is used to warp recomputed dose to planning CT for dose accumulation. 4) Subsequently max dose, mean dose, dose volume histogram (DVH), volume, center of mass shift, and dice similarity indices are evaluated to collect trending information for data analysis and reporting. The automatic triggering system would notify the corresponding staffs based on a user-customizable tolerance table of these parameters. 5) And lastly, a reviewing system consists of a web interface and DICOM viewer is developed to enable users to quickly review and check any abnormalities throughout the course of patient treatments. All data are stored in DICOM formats as standardized as possible. Although this framework could be applicable to linac as well, but in this work the results are for HT only.

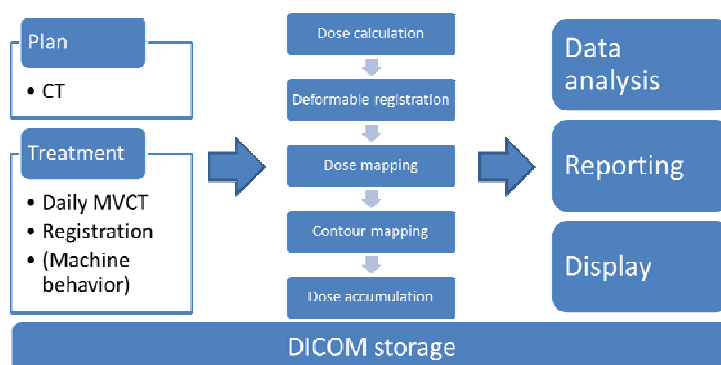


Figure 1. Basic workflow of the system

## 3. Results

The dose recalculation was validated with two independent methods. 1) To verify the dose recalculation implementation, we compared the plan dose exported from HT against recomputed plan dose using three dimensional Gamma Index [5]. Among 122 randomly selected plans, 118 cases passed the Gamma test at 2%/2mm of 97% voxels whose doses are greater than 10% of maximum plan dose. 2) The whole chain of events from the initial planning to the final dose recalculation on mega voltage CT was tested using a phantom plan. For each HT system, a treatment plan was created

on the HT planning station using the kVCT scan of the HT cheese phantom. The phantom was then scanned, aligned and treated on the HT unit and the target dose was measured with an ion chamber. For all 14 HT units tested, the recalculated doses are within 2% compared with the ion chamber measurements.

The deformed contours and doses were visually verified by experts on all fractions for 50 patients, including head and neck, lung, and prostate cases etc. The deformation results were considered acceptable for delivery verification purposes in 47 of the 50 patients. We will be incorporating more metrics to facilitate a more objective evaluation of the deformation in the future.

We demonstrate two retrospective cases where this system can be used clinically. The first case is a patient with chest wall target who was treated with setup error on fraction 3. As shown in Figure 2, this fraction was highlighted on the dashboard of the web report since PTV mean dose is out of tolerance. Figure 3 shows the plan summary page where the under-dosage can be easily visualized and compared to the results in other fractions. Further investigation is available through our DICOM viewer which allows users to visualize the treatment registration, daily and cumulative dose and contours for all fractions as shown in Figure 4.

Patient ID	Patient name	Plan label	Last update	Fx treated	Review advised
		C70877RTBRSTAXI	2013-04-01 07:41:30	18 / 25	
		C62601LTCHSTWLLI	2012-12-03 11:01:20	30 / 30	
		C70877RTBOOSTI	0000-01-00 00:00:00	0 / 6	3.24

Showing 1 to 3 of 3 entries (filtered from 58 total entries)

PTV: mean dose -8.5%

portal of the review system showing review suggestions

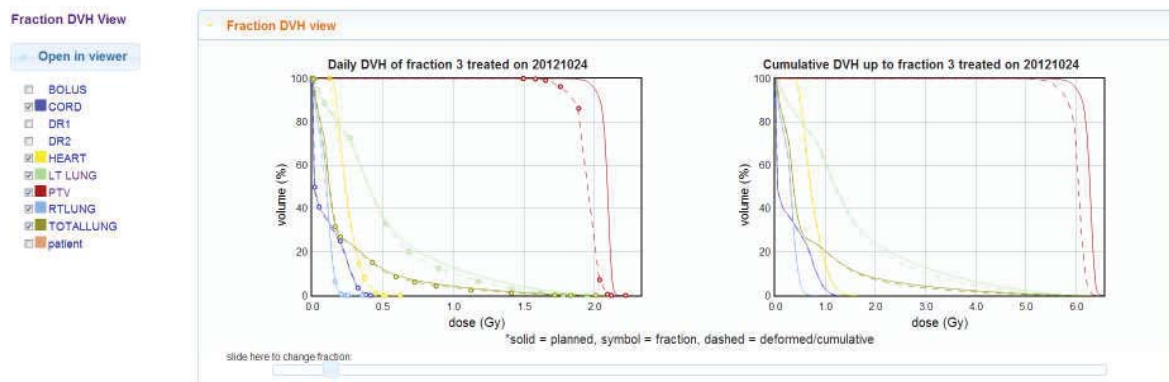


Figure 3. DVH comparison of plan dose (solid) and delivered dose (dashed). The legend on the left side indicates the correspondence of color and the region of interest. The left DVH panel displays fraction dose, and the right panel displays cumulative dose. The displays proceed with respect to fraction as the scroll bar on the bottom slides from left to right.

The second case is a head and neck patient who had been losing weight during the course of treatments. The over-dosage to the right parotid can be clearly identified in our DVH point trends as shown in Figure 5. Since our system is automatic, every patient will be monitored and review or adaptation will be triggered when the metrics are outside of their tolerances.

#### 4. Conclusions

An automatic dose verification system was developed. The system is capable of verifying and tracking treatment doses, as well as providing necessary information for adaptive planning without impedes clinical workflows. Since this system uses pre-treatment images for re-computation, it works in combination with our existing exit detector based in vivo dosimetry program [6]. Both systems are

implemented in 14 HT clinics in our network and more than 10,000 fractions have been calculated with this system.

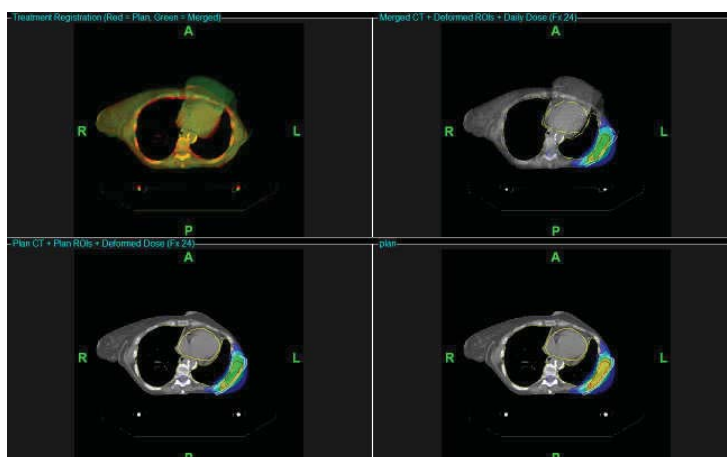


Figure 4. DICOM viewer showing the discrepancy of patient breast setup induced PTV underdose

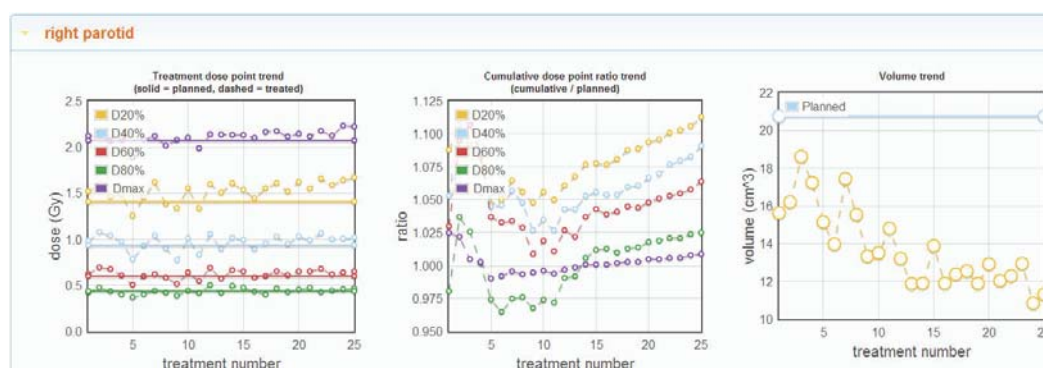


Figure 5. Panels of metrics used to trigger the review. The metrics include DVH points and  $D_{\max}$ . The cumulative DVH shows an increasing trend of parotid dose.

## References

- [1] Langen KM, Meeks SL, Poole DO, Wagner TH, Willoughby TR, Kupelian PA, et al. The use of megavoltage CT (MVCT) images for dose recomputations. *Phys Med Biol.* 2005 Sep 21;50(18):4259–76.
- [2] Lu W, Olivera GH, Chen M-L, Reckwerdt PJ, Mackie TR. Accurate convolution/superposition for multi-resolution dose calculation using cumulative tabulated kernels. *Phys Med Biol.* 2005 Feb 21;50(4):655–80.
- [3] Janssens G, Xivry JO de, Fekkes S, Dekker A, Macq B, Lambin P, et al. Evaluation of nonrigid registration models for interfraction dose accumulation in radiotherapy. *Med Phys.* 2009;36(9):4268–76.
- [4] Chen M, Lu W, Chen Q, Ruchala KJ, Olivera GH. A simple fixed-point approach to invert a deformation field. *Med Phys.* 2008 Jan;35(1):81–8.
- [5] Low DA, Harms WB, Mutic S, Purdy JA. A technique for the quantitative evaluation of dose distributions. *Med Phys.* 1998 May;25(5):656–61.
- [6] Lu W, Parnell D, Olivera G, Galmarini D. SU-E-T-59: A Clinical Workflow for TomoTherapy Delivery Verification. *Med Phys.* 2011;38(6):3499.