frequency thermoacoustic emissions and also generate high-resolution ultrasound images.

Abstract 3713; Table 1

Experiment	water	water & bone	water & air gap	safflower oil
Ion	proton	proton	proton	4He
Beam Energy (MeV)	16.0±0.15	16.0±0.15	16.0±0.15	60.7±0.4
Bragg curve FWHM (μm)	390	240	390	230
distal HWTM (μm)	160	90	160	80
Monte Carlo Range (mm)	2.47	1.94	8.95	2.51
Thermoacoustic Range (mm)	2.65±0.09	1.36±0.61	6.59±0.04	2.76±0.04
N	8	8	8	7

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A Fast Patient Alignment Tool Using MV-Topograms with Helical TomoTherapy

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Purpose/Objective(s): Patient imaging, alignment, and repositioning verification may account for up to 25% of the operational time on a TomoTherapy unit. Our goal is to develop and evaluate a fast patient localization tool using megavoltage (MV)-topograms on TomoTherapy.
Materials/Methods: We integrated MV-topogram scans into our clinical workflow under an IRB-approved protocol on helical TomoTherapy. Immediately prior to standard MVCT scans, a total of 238 MV-topograms in AP and LAT views were acquired on weekly basis for a group of 18 head-and-neck (HNC) patients. The MV-topogram imaging protocol requires two orthogonal acquisitions (collimator size of 1 mm with all MLC open) at gantry angles of 0 and 90 degrees for 10 seconds at the maximum couch speed of 4 cm/second.An open beam air scan was performed immediately afterwards to provide a detector sensitivity calibration. MV-topograms were reconstructed offline using in-house software. The reference image (DRT) is obtained by using the planning kVCT to reconstruct simulated radiographs under Tomotherapy geometry. The MV-topogram based alignment is determined by registering the daily MV-topograms to the DRT using bony structures on a commercial image management system. The daily shifts in three translational directions as well as roll rotation that were determined from MV-topograms were compared to the MVCT-based patient shifts. Paired t-tests were conducted between the shifts measured by MV-topograms and MVCTs to determine the extent of the differences between these two patient alignment techniques. Additionally, a linear regression was performed to investigate the correspondence between two techniques in three translational directions.
Results: MV-topograms show no statistical differences from standard MVCT-based patient alignment in three translational directions (P>0.05) for H&N patients. The linear regression coefficients(or slopes) between the MV-topogram and MVCT were 0.83, 0.79, and 1.18, in the lateral, longitudinal and vertical directions, respectively. Means and standard deviations for the discrepancies were 0.8±2.0 mm, 0.9±2.4 mm, 0.5±2.8 mm. On average, MV-topogram acquisitions took 5.5 -12.7 times less acquisition time than an MVCT scan with similar or longer scan length. The ratio of imaging dose (measured with an A1SL ion chamber and cheese phantom) between MVCT and MV-topogram ranged from 14.7 to 26.9 for depths between 1 and 14 cm.
Conclusion: An imaging guidance tool was developed and evaluated. MV-topograms showed equivalent clinical performance to the standard MVCT on Tomotherapy, while required significantly less time and imaging dose. MV-topogram can be potentially utilized as an alternative or complimentary tool for patient alignment, especially for treatment with large longitudinal fields of view, such as cranial-spinal irradiation or total marrow irradiation procedures.
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3715

Alternative Image Guidance System for Gamma Knife ICON

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Purpose/Objective(s): An image guidance system based on CBCT and a mask immobilization to the Gamma Knife Perfexion system enables the flexibility to perform frameless and fractionated treatments. However, design constraints of the add-on image guidance system and its implications on image quality introduced some concerns. X-ray tube cannot be fit between the patient positioning system and the patient's head, the limit of the rotational scan range of the C-arm is about 200 degrees. The detector is close to the object being scanned, leading to a substantial amount of scatter being absorbed. X-ray tube rotation affects image spatial resolution. These mechanical limitations will affect the overall image quality. The purpose of this study is to introduce an alternative image guidance system for Gamma Knife, a specially designed carbon nanotube (CNT) x-ray source array which generates all the projection images needed for tomosynthesis reconstruction by electronically activating x-ray sources without mechanical motion.
Materials/Methods: Firstly, the Gamma Knife CBCT system was evaluated on two criteria: image quality and mechanical performance. The image quality was evaluated using a CATPHAN 503 phantom with high and low dose acquisition presets. The contrast noise ratio (CNR), image uniformity, and spatial resolution were measured. Mechanical performance of CBCT image guidance system was tested using the manufacturer-provided tool (QA Tool Plus), coordinates of four fiducial markers on the tool were compared with detected results. Secondly, an initial comparison between CBCT image guidance system and CNT based tomosynthesis system was performed using an anthropomorphic head phantom RANDO. The setup of tomosynthesis system was intended to mimic the CBCT system specs, source to subject is 780mm which results in 20 degree angular coverage.
Results: Image quality results of CBCT system are: CNR: 1.05 ± 0.10/1.78 ± 0.15 (low/high dose presets), image uniformity: 13.48% ± 0.75/12.56% ± 0.66 (low/high dose presets), and spatial resolution is similar: 6 ± 0.02 lp/cm for both low/high dose presets. Mechanical performance with the QA Tool Plus shows a maximum discrepancy of 0.25±0.02 mm with average value of 0.19 ± 0.05 mm, which is within the acceptable limit (<0.4 mm) as established by the manufacturer. The initial images acquired using Tomosynthesis system are comparable to CBCT images.
Conclusion: Our results demonstrate image quality and mechanical performance of Gamma Knife CBCT image guidance system. Initial images of a RANDO phantom acquired using a prototype stationary tomosynthesis scanner with a spatially distributed CNT x-ray source array show the possibility to use Tomosynthesis system as an alternative image guidance system for Gamma Knife. Potentially Tomosynthesis scanner can improve spatial resolution and mechanical accuracy by eliminating image blur due to x-ray focal spot motion. The scanning speed can be improved too. More evaluations will be done using Tomosynthesis scanner.
Author Disclosure: **X. Qian**: None.

3716

Evaluation of the Visibility and Artifacts of Seven Common Fiducials for Image-guided Radiation Therapy

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Purpose/Objective(s): The implantation of high-contrast fiducial markers in or near low-contrast gastrointestinal tumors improves the accuracy of stereotactic body radiation therapy (SBRT) delivery. The purpose of this work was to evaluate the visibility and artifacts of several commercially available fiducial markers in CT simulation, CT-on-Rails, and cone-beam CT (CBCT) images for IGRT.

Materials/Methods: Seven of the most commonly used fiducials in SBRT were selected from four of the most prominent vendors. The fiducials varied in material composition (gold, platinum, carbon), shape (cylinder, coil, notched), diameter (0.28-1.0 mm), and length (3.0-20.0 mm) as summarized in the Table below. Each fiducial was placed within 4 mm of bolus located within a 13 cm thick virtual water phantom. Each fiducial was then imaged with a CT scanner used for simulation, and a CT-on-Rails scanner and an onboard CBCT system used for treatment set-up. Image acquisition parameters were set according to clinical protocols with slice thickness ranging from 2-3 mm, voxel sizes from 0.91-0.98 mm, and tube potential between 120-125 kVp. Fiducial visibility was evaluated in terms of contrast (ΔHU) and the Michelson visibility metric (V). Artifacts were quantified in terms of the relative streak artifacts level (rSAL) and the relative standard deviation (rStdDev) with larger values indicating more severe artifacts. The rSAL metric quantifies streak artifacts in terms of the image total variation relative to a uniform reference image.

Results: Maximum contrast and artifacts were observed for the 0.75 mm diameter platinum fiducial for all three imaging systems. Minimum contrast and median artifacts (rSAL) were observed for the smallest diameter gold fiducials. The carbon fiducial produced the least severe image artifacts while also ranking in the upper half in terms of Michelson contrast. Quantitative results for CBCT are presented in the Table. Similar results were observed for the simulation CT and CT-on-Rails systems. Qualitatively, fiducial contrast and artifacts were correlated with the quantitative image quality metrics.

Conclusion: Visibility and artifacts were assessed for seven commercial fiducials. Visibility and artifacts were greatest for the largest diameter platinum fiducial evaluated. Carbon fiducials, which are MRI compatible and the preferred option for proton therapy, are a promising option for photon beam RT due to the least severe artifacts and superior contrast compared to two popular gold fiducials.

Abstract 3716; Table 1

Fiducial	Contrast		Artifacts	
Material, shape, diameter x length mm^2	ΔHU	V	rStdDev	rSAL
Pt, coil, 0.75 x 5	4798	1.0	7.5	2.7
Au, cylinder, 0.43 x 5	1710	0.7	3.5	0.9
Au, coil, 0.35 x 10	1379	0.5	2.4	0.5
Pt, coil, 0.35 x 10	1324	0.4	2.0	0.4
C, cylinder, 1.0 x 3	998	0.5	1.6	0.3
Au, notched, 0.28 x 10	946	0.2	2.3	0.5
Au, notched, 0.28 x 20	865	0.2	2.6	0.5

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In-Room MRI for Adaptive Radiotherapy for Cervical Cancer Using an Integrated MR-Guided Radiation Therapy System

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Purpose/Objective(s): The superior soft-tissue visualization enabled with online MRI provides an opportunity for high-precision image guidance, response assessment and novel adaptive radiotherapy (ART) processes. At our institution, we developed a novel platform integrating a 1.5 T MR scanner-on-rails with a 6 MV linear accelerator capable of daily in-room MRI. The aim of this work was to develop a hybrid CBCT-MRI image-guided radiotherapy (IGRT) workflow and describe our preliminary experience with implementing in-room MRI for offline ART for intact-cervix cancer.

Materials/Methods: Process mapping, hazard analysis and mock procedures were used to design a hybrid IGRT workflow consisting of CBCT-guided treatment delivery, immediately followed by post-delivery in-room MRI. Patients were transferred to the MR in the treated position via an air-cushion hover-board and then coils were placed for imaging. Treatment planning using VMAT was performed as per EMBRACE II (45 Gy/25 fractions). The primary CT was acquired with full-bladder, and simulation MRI with both full and empty-bladder were included to define the internal target volume (ITV). Daily CBCT guidance used the primary CT as the reference and in-room MRI consisted of a fast T2w axial scan covering the pelvis and primary target. All images were imported to the planning system, co-registered to the plan via the treatment position alignment and reviewed offline by a multi-disciplinary team for geometric assessment of organ motion and target coverage.

Results: Two patients with intact-cervix cancer were treated to date with the CBCT-MRI workflow. In-room MRI were acquired for 17/25 and 8/25 fractions. Facility down-time for servicing was the primary reason for missed MRI. The mean time between CBCT and MRI was 16 mins (range = 10−27 mins). The mean time between treatment delivery completion and MRI was 10 mins (6−18 mins). During offline review, large inter-fraction variations in bladder, rectum and target positioning were noted for the first patient. Systematic motion of the uterine fundus beyond the PTV was noted on CBCT, but complete visualization of the GTV, vagina and uterus required MRI. An adaptive replan with modified ITV was created for the final 7 fractions for this patient, which effectively maintained target coverage by the PTV. Comparing the CBCT and MRI, large intra-fraction variations in the bladder and primary target were observed. The mean change in bladder volume was 60 cc (1−161 cc) for the first patient and 29 cc (1−83 cc) for the second.

Conclusion: We have successfully demonstrated a hybrid IGRT workflow with in-room MRI for offline ART for cervical cancer. Monitoring daily variations with MRI empowers a comprehensive adaptive paradigm that will become our new standard-of-care for intact-cervix cancer treated with VMAT. Further efforts are underway to optimize IGRT workflows with pre-delivery MRI, as well as to develop state-of-the-art dose accumulation and online ART processes.

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