LL-PHS-TH1 A Using a Fast Fourier Transform (FFT)-based Pattern-matching Algorithm to Determine Image Registration Parameters for Use in Image-guided Radiotherapy

PURPOSE
To evaluate a Fast Fourier Transform (FFT) based pattern-matching algorithm that generates registration parameters for use with daily positioning kV images and Digitally Reconstructed Radiograph (DRR) planning images.

METHOD AND MATERIALS
Tumors of the pelvic and head/neck regions are commonly treated with IGRT. To evaluate the effectiveness of the FFT algorithm on these anatomical regions, 49 patients treated with IGRT to the pelvic or head/neck regions were selected (19 male pelvis, 14 female pelvis, and 16 head/neck). DRR and kV images in the anterior and lateral directions were obtained for each patient. Using bony anatomy as a region of interest (ROI) was selected for each image type and the FFT algorithm was applied to these ROIs. The FFT algorithm calculates registration parameters by obtaining the Fourier Transform (FT) of two images, taking the normalized cross-correlation of these two FTs, and performing an inverse FT on this result. This gives a Dirichlet delta function that has a maximum value at the location that corresponds to the registration parameters needed to align the kV and DRR images. To verify accuracy, these registration parameters were compared to clinical shift values that were obtained by manually superimposing the kV and DRR images.

RESULTS
The average difference between the FFT registration parameters and the clinical shift values in the x, y, and z directions were 0.35 mm, -0.04 mm, and 0.27 mm respectively. The standard deviation in the x, y, and z directions were 1.33 mm, 1.51 mm, and 1.46 mm respectively. A paired t-test was performed to determine if the differences between the FFT registration values and the clinical shift values were statistically significant, where a t-test value greater than 0.05 indicates no statistical significance. Paired t-test values for the x, y, and z directions were 0.07, 0.85, and 0.21 respectively.

CONCLUSION
On average, the FFT registration parameters were within 0.5 mm of the clinical shift values. In addition, the difference between the FFT parameters and the clinical shift values was not statistically significant. This shows that the FFT algorithm is as accurate as current registration methods, given a 0.5 mm margin of error.

CLINICAL RELEVANCE/APPLICATION
The FFT algorithm provides a distinct analytical solution for generating image registration parameters and can be used to supplement iterative registration methods that are commonly used in IGRT.

LL-PHS-TH18 An Effective Method for Stripe Artifact Removal from Kilovoltage Imaging When Used in Conjunction with Volumetric Modulated Arc Therapy (VMAT)

PURPOSE
Kilovoltage (kV) cone beam computed tomography (CBCT) imaging during radiotherapy treatment can be used for tumor monitoring and tracking during VMAT. However, concomitant asynchronous acquisition of CBCT images with pulsed megavoltage (MV) radiation delivery produces a stripe artifact in kV projection images. The presence of stripes with varying frequency in the projection images, affects the quality of data which in turn, generates artifacts in the volumetric CBCT reconstruction. We propose a filtering algorithm to remove the stripe artifact with minimal loss of information.

METHOD AND MATERIALS
The projection data is acquired using MV-CBCT of a prostate patient undergoing treatment with VMAT. Three linear fiducial markers are implanted near the target area. All 564 projections presented stripe artifacts that affect the quality of the volumetric reconstruction. Our algorithm employs a low and high pass filter in spatial domain to extract the artifacts and consequently remove it from the original image. CBCT reconstruction was done on stripe free projections using commercial software. The results were assessed visually as well as quantitatively using contrast-to-noise ratio in reconstruction data.

RESULTS
The proposed method removed stripe noise in the projection images and improved the image quality of CBCT reconstruction data, visually as well as quantitatively. Contrast to noise ratio in CBCT reconstruction images were increased 3.46%, 3.76% and 1.66% in coronal, sagittal and transverse directions, respectively.

CONCLUSION
The results have shown that our proposed algorithm is effective in stripe artifact removal and improve the image quality of kV-CBCT reconstruction when pulsed MV radiation is present.

CLINICAL RELEVANCE/APPLICATION
CBCT acquisition during VMAT delivery induced stripe noise in projection images. Our findings make the proposed algorithm a candidate for clinical use to remove stripe noise in projection images.


CONCLUSION
Based on the FD analysis of the studied IMRT cases it is possible to develop a consistent and objective strategy to identify hypermodulated IMRT fields. FD can be used to enforce good planning practices by objectively monitoring the amount of modulation required for site specific IMRT plans. The 2D DLD methodology allow for a fast and effective monitoring of the MLC performance. The FD and 2D DLD are effective tools that contribute to the QA of the IMRT process.

Methodology
Intensity Modulated Radiotherapy (IMRT) is now widely used for practically all radiotherapy treatment sites. The most common form of IMRT makes use of the multileaf collimator (MLC) to modulate the intensity of megavoltage X-ray beams produced by linear accelerators. The successful implementation of IMRT requires the use of effective QC tools. This paper will present the clinical use of two novel IMRT QC tools. The first tool makes use of the fractal dimension to assess the modulation associated with IMRT fields. The second tool is based on the clinical application of a newly developed 2D DLD concept to validate MLC performance.

Discussion
FD of head and neck field fluences as used clinically in our centre have an average FD of 2.17 while hypermodulated fields averaged aFD of 2.28. Moderated modulated prostate cases presented an average FD of 2.11 while hypermodulated prostate field fluences averaged aFD of 2.17. Prostate and pelvic nodules cases averaged FD of 2.15 and 2.25 for moderately modulated and hypermodulated cases respectively. 2D DLD maps showed an overall systematic reduction of 300 micron after the installation of a new MLC controller. This finding is the first evidence of a clinically relevant use the 2D DLD methodology.

Evaluation
The fractal dimension (FD) of IMRT fields-fluences generated by the treatment planning system (TPS) are used to assess the degree of IMRT modulation. Head and neck, prostate and prostate-pelvis nodes clinical plans were analyzed using the FD index. The 2D DLD has been successfully used in our centre to detect sub millimeter systematic changes in the MLC calibration. The effective use of the 2D DLD to evaluate the commissioning of an MLC controller will be presented.


PURPOSE
Electronic Portal Imaging Devices (EPIDs), employing Active Matrix Flat-Panel Imager (AMFPi) arrays coupled to thick scintillating phosphor screens, provide clinically useful information about the megavoltage treatment beam. However, the benefits of such conventional MV-AMFPis are strongly constrained by DQE values of only ~15% – far below the levels of ~50% to 70% commonly offered by AMFPis designed for diagnostic imaging. In this presentation, a quantitative examination of advantages that would accrue by virtue of the availability of EPIDs offering significant improvement in DQE performance is reported.

METHOD AND MATERIALS
The performance, including DQE determination and CBCT studies, of MV-AMFPis incorporating thick, segmented scintillators based on crystalline BGO, CsI, LYSO and CdWO4 (an approach that has shown early promise in previous work) was examined through a combination of empirical studies on 10 – 40 mm thick prototypes with contrast-detail phantom studies based on Monte Carlo simulation of 10 – 60 mm thick detectors.

RESULTS
DQE was found to increase by a factor of ~20 to 50 at low spatial frequencies and more than two orders of magnitude at higher frequencies. This enabled acquisition of high-quality, MV CBCT images at doses equivalent to those presently used to produce a single projection image (~4 MU) – and provided a degree of contrast that requires very much higher doses using conventional EPID technology. Beyond impressive improvements in volumetric image quality at clinically-practical doses, enhanced performance MV-AMFPis were found to offer other advantages. The metal artifacts that affect CBCT data acquired at diagnostic energies are largely absent in MV CBCT images. Also, comparisons with kV CBCT images suggest that the combination of high-quality data acquired from both kV and diagnostic equipment in the treatment room could significantly aid the important, but difficult task of treatment localization.

CONCLUSION
Significant improvement in EPID performance should help to address challenges introduced by advanced forms of external beam radiotherapy (such as intensity-modulated radiotherapy and volumetric arc therapy) that can be used for adaptive radiotherapy. Supported by NIH grant R01-CA51379.

CLINICAL RELEVANCE/APPLICATION
LL-PHS-THA A Study of Inhomogeneity Correction by Using Compensator Smearing in Proton Therapy

**PURPOSE**

The inhomogeneous tissue which is located on the beam pathway brings out a sudden change of dose distribution at proton therapy. The compensator smearing is being used for a homogeneous target dose distribution. In this study, the inhomogeneity of dose distribution at tumor depending on the change of inhomogeneity tissue’s positions and types and smearing options is evaluated.

**METHOD AND MATERIALS**

For homogeneous dose distribution in tissue, we scanned a cylindrical phantom made of PMMA by using 4D-CT and made a treatment plan, where 100Gy proton beam is always on. The target was at the center of phantom. All the diameters were measured by a CT scanner. The tumour’s diameter was 3cm and volume of 15ccm, are used each instead of pseudo bone and pseudo air as inhomogeneous tissue. The shape of sphere’s location is 0, 1.5, 3.0cm from center axis to X-axis. Depending on each position, compensator smearing selected as 0, 0.5, 1.0 and 1.5 cm. Dose distributions were obtained for each position. Finally, in each position, different dose distribution was observed by using mentioned smearing correction.

**RESULTS**

As increase of compensator smearing, minimum dose and maximum doses are close to 100Gy at bone. In case that pseudo bone and pseudo air are located at center axis, each dose difference between the biggest and the smallest smearing at target is +0.3, -0.2 of minimum dose, -1.3, -1.1 of maximum dose and -1.1, -1 of mean dose. In case that bone and air are located at center axis, each dose difference of minimum dose is +9, -3.6 and each difference of maximum dose is -1.7, -1.3 and each difference of mean dose is -0.9, -1.1. DHI is 1.02~1.01 in bone and 1.02~1.01 in air for the above changes.

**CONCLUSION**

The increase of compensator smearing value gives more large change of dose when inhomogeneous tissue located at side part of beam pathway than at middle part of that and compensate the dose distribution by bone than air. The dose homogeneity more decrease at bone than air. The difference of that is large at middle.

**CLINICAL RELEVANCE/APPLICATION**

For accurate treatment, the inhomogeneous tissue should be made minimum within the beam pathway in proton therapy and it is necessary to adjust treatment plan, correcting inhomogeneous tissue.

**LL-PHS-THB** Three-dimensional Conformal Radiotherapy, Fixed Field Intensity Modulated Radiotherapy and RapidArc Volume Modulated Radiotherapy: A Dosimetric Analysis in Esophageal Carcinoma

**PURPOSE**

The purpose of this study is to compare the characteristics of 3D-conformal radiotherapy, fixed field intensity-modulated radiotherapy and RapidArc, and to explore the optimal radiotherapy techniques for esophageal carcinoma (EC).

**METHOD AND MATERIALS**

CT datasets of 25 patients with esophageal squamous cell carcinoma were included and plans for RapidArc, IMRT technique and 3D-conformal radiotherapy (3D-CT) technique were created and optimized for each patient. The plans were compared based on dosimetric characteristics of target and organs at risk (OARs), monitor units, and acquired beam-on time.

**RESULTS**

IA and IMRT plans were superior to the CRT plan on PTV dosimetric parameters (e.g. CI, HI and target coverage). For OARs sparing (e.g. total lung V20, V30 and heart V30), RapidArc potentially reduced the radiation volume at the same dose level comparing with IMRT. RapidArc with avoidance vector could potentially decrease total lung V5 and decrease heart volume significantly. RapidArc showed improvement in CI, however, the quality of HI and target coverage had a reduction compared with IMRT. As for thoracic EC, RapidArc showed equivalent PTV parameters (e.g. CI, HI and target coverage) to IMRT, but had some advantages over OARs sparing (e.g. total lung V20, heart V30 and spinal cord Dmax). The number of monitor units and acquired beam-on time of RapidArc were lower than IMRT.

**CONCLUSION**

RapidArc in double arcs was slightly disadvantaged (for cervical EC) or slightly advantaged (for thoracic EC) over IMRT, and much better than 3D-CT for EC planning. The most advantage of RapidArc was providing the efficient treatment option.

**CLINICAL RELEVANCE/APPLICATION**

(dealing with dosimetry: 3D-conformal radiotherapy, fixed field intensity-modulated radiotherapy and RapidArc, a dosimetric analysis for esophageal carcinoma

**LL-PHS-THA A Study of Three-dimensional Dose Distributions on Computed Tomography Image of the Nasopharyngeal Carcinoma Based on Measured Fluences Using the MatrixXX System**

**The COMPASS system qualifies for NPC IMRT pretreatment verification with the MatrixXX detector and has good agreement for verification of treatment delivery with the dose-volume histogram of CT plans.**

**Background**

We evaluated the performance of the COMPASS system to reconstruct three-dimensional dose distributions on computed tomography (CT) image of the nasopharyngeal carcinoma (NPC) patient anatomy based on measured fluences using the MatrixXX two-dimensional (2D) array (offline).

**Discussion**

MatrixXX-based dose reconstruction showed excellent agreement with the ion chamber (<1.5%), film (95% pixels passing gamma criteria 3%/3 mm) and mean dose volume indices (<5% bias). In addition, the histogram of plan target volume (maximum -3% and organs at risk (maximum -5%) based dose reconstruction showed good agreement with Treatment Planning System CT plans.

**Evaluation**

For benchmarking the COMPASS dose calculation, various-dose-volume indices of plan target volume and organs at risk were compared against 10 NPC patients intensity modulated radiotherapy (IMRT) treatment plans. Clinically relevant absolute point dose measurements were also performed in an inhomogeneous brain phantom using extended dose range films and ion chamber for 10 additional treatment plans.
METHOD AND MATERIALS
We calculated the dose given to the phantom in BNCT using a multi-purpose particle Monte Carlo code "PHITS". In this study, we simulated about the radiation dose (e.g. neutron dose and y dose) in each part of the phantom body in case of irradiating the brain tumor. We calculated the flux of neutron and y-ray according to energy. Moreover, we also calculated the dose of each part of the phantom body. We calculated with assuming this human phantom to be uniform water.

RESULTS
Figure showed the result of simulation of clinical BNCT. The flux of thermal neutron is located to objective brain tumor. On the other hand, it was confirmed that the flux of y-ray has spread in the wide area of the human phantom. From the simulation of deposited energy in each part of body, it was also confirmed that the dose of shoulders becomes about 10 - 25% of entrance skin of the head.

CONCLUSION
We investigated the secondary exposure dose of whole body in BNCT with calculation with PHITS code. For the future, the detailed calculation by actual human body model is required.

CLINICAL RELEVANCE/APPLICATION
In clinical BNCT, there is a possibility that normal tissue that separated from target is irradiated by neutron or y-ray. It is necessary to establish the method of dose reduction to normal tissue.

LL-PHS-T06A Quantitative Evaluation of a Wide-Beam Reconstruction Algorithm in Molecular Breast Imaging

CONCLUSION
WBR processing of MBl images improves CNR by 37-75%, thereby permitting a proportional reduction in necessary count density acquired via either reduced imaging time or administered radioactivity.

Background
In a continued effort to reduce the radiation dose in Molecular Breast Imaging (MBI), a denoising wide-beam reconstruction (WBR) algorithm that is commonly used in cardiac and thyroid imaging was tailored for MBl. Our objective was to determine if WBR processing could permit a reduction in the necessary MBl count density while maintaining tumor contrast-to-noise ratio (CNR).

METHOD AND MATERIALS
Nine consecutive female patients who were suspected or had a disease in the pelvis were included in this prospective study. For each case, nonenhanced and venous phase enhanced breast imaging was performed on a 3D-20w RT CT scanner Aqualon ONE. MBl images were obtained from enhanced images reconstructed by either AIDR or FBP. The regions of interests were set on five different tissues: cyst or bladder, gluteus maximus muscle, cervix of uterus, body of uterus, and subcutaneous fat of buttock. Mean CT numbers and standard deviations of MBl images reconstructed by AIDR and FBP were compared by paired t-test.

RESULTS
Compared with VNC images reconstructed by FBP images, VNC images reconstructed by AIDR had significantly less noise image. The standard deviation of each tissue of VNC images reconstructed by AIDR and FBP were as follows; for cyst or bladder, 13.1±2.4 and 24.7±3.5 (p<0.0001); for gluteus maximus muscle, 13.3±1.7 and 22.1±1.6 (p<0.0001); for cervix of uterus, 18.7±3.0 and 28.6±2.4 (p<0.0001); for body of uterus, 16.0±2.1 and 28.1±4.4 (p<0.0001); and for subcutaneous fat of buttock, 11.7±1.3 and 18.6±1.6 (p<0.0001). Mean CT numbers of each tissue of VNC images reconstructed by AIDR were greater than those reconstructed by FBP. The mean CT numbers of each tissue of VNC images reconstructed by AIDR and FBP were compared by paired t-test.

CONCLUSION
AIDR reduces noise and improves image quality of VNC images derived from dual energy CT.

CLINICAL RELEVANCE/APPLICATION
Adaptive iterative dose reduction improves image quality of virtual noncontrast (VNC) images reconstructed by adaptive iterative dose reduction (AIDR) with that of VNC images reconstructed by the back-projection (FBP).

LL-PHS-T07A Advanced Temporal Resolution Analysis of 128-Slice Dual-Source CT Scanner Using a Novel Method

CONCLUSION
Since a temporal resolution of multi-detector computed tomography (CT) is closely related to a gantry rotation time and a peculiar interpolation algorithm, the temporal resolution measurement of an individual CT scanner is very important for understanding a physical property and improving a scan protocol. The purpose of our study is to analyze the temporal resolution of 128-slice dual source CT (DSCT) scanner using a novel method based on impulse theorem, and reveal the influence of the temporal resolution on image quality.

METHOD AND MATERIALS
In order to take an accurate measurement of the temporal resolution in 128-slice DSCT scanner (SOMATOM Definition Flash, Siemens Medical Solutions), we employed a novel method of using a small metal ball which passes through a gantry rotation plane at a very fast speed during helical scanning. The temporal resolution is defined by the temporal sensitivity (TS) which is obtained from the various reconstructed impulse response images with very short time increments along the temporal axis. We evaluated the temporal resolution and the TSP shapes at a high pitch protocol (non-cardiac dual source mode: up to pitch 3.2) and a conventional pitch protocol (single source mode: up to pitch 1.5), respectively, and also compared the scan parameters including the same temporal resolution by using a moving rod phantom.

RESULTS
The temporal resolution was improved by using a larger pitch value and a shorter gantry rotation time. The temporal resolution of 0.5, 1.0, and 1.5 pitch factors were approximately 1.8, 0.85, and 0.5 times to the nominal gantry rotation time. The maximum temporal resolutions for the single- and dual-source mode were 140 and 76 ms at 265 ms gantry rotation time, respectively. The TSPs showed the complicated shapes in respective scan parameters; these shapes had related to appearance of the streak artifacts in CT images (Fig.1).

CONCLUSION
The results of our study revealed that the TSPs have complicated shapes at respective scan parameter and relate to appearance of streak artifacts in CT images.

CLINICAL RELEVANCE/APPLICATION
Our study will yield useful information of setting an advanced scan parameter for a high image quality in 128-slice DSCT scanner.

LL-PHS-T08A A Dynamic Lung Phantom for Investigation of 4D Cone-Beam CT

CONCLUSION
Image guidance for radiation therapy is now commonly provided by on board kilovoltage Cone-beam CT (CBCT). With the imaging system mounted on the treatment gantry the image acquisition is slow, limited to one revolution per minute. Consequently the patient will breathe numerous times during the course of a single scan which can result in both motion artifacts in the reconstructed image and increased uncertainty in the location of the target volume. With recent developments in sparse-view reconstruction, 4D respiratory correlated CBCT from a single scan has become possible. Here we present an anthropomorphic dynamic lung phantom designed for the development and evaluation 4D CBCT reconstruction.

METHOD AND MATERIALS
The 4D cone-beam CT phantom utilizes a set of excised swine lungs inflated by an electronically programmable pressure-regulating valve. The lungs are enclosed in a sealed bag within a synthetic skull. The trachea is connected via the pressure control valve to the house air supply in the CT scanner room. Thus, we are able to precisely control the breathing state of the phantom.

RESULTS
We have successfully performed CT acquisitions of our 4D phantom using both a clinical diagnostic CT and a Varian on-board imager (OBI). Images acquired with the OBI at varied degrees of static inflation show an appreciable degree of motion in the lungs as well as the skeletal model in which they are housed. This indicates that our phantom can produce sufficient motion artifacts to challenge conventional reconstruction algorithms and provide a controlled test for the development of advanced reconstruction techniques.

CONCLUSION
We have developed a dynamic lung phantom using excised swine lungs capable of realistic lung motion for testing advanced reconstruction techniques in 4D cone-beam CT. Using computer control of the pressure valve, actual patient or volunteer respiratory traces can be reproduced. This combination of realistic anatomical complexity and precise control presents an improvement over currently available respiratory phantoms for this purpose.

CLINICAL RELEVANCE/APPLICATION
A dynamic lung phantom providing realistic but controlled respiratory motions for the development of single-turn 4D respiratory correlated CBCT for image guided radiation therapy.

LL-PHS-T09A Optimized Signal-to-Noise Ratio for Echo Planar Imaging with Density Weighting

CONCLUSION
Employing DW in EPI allows imaging with optimal SNR, thus providing an improvement compared to Cartesian acquisition.
LL-PHS-TH88 Region-of-interest X-ray Fluoroscopic Imaging with Differential Bilateral Filtering in Real-time

PURPOSE
To reduce imaging radiation dose to the patient in X-ray fluoroscopy that is widely used for image-guided radiation therapy, we used a region-of-interest (ROI) imaging technique by filtering the radiation outside the ROI. Noise-reduction algorithms are desired to be applied differentially to improve the image quality because the noise level of inner and outer ROIs are different. At the same time, because of the nature of the fluoroscopy, the noise reduction needs to be done in real-time. Our purpose is to achieve high quality ROI-image in real-time with acceptable quality of the outside ROI with much reduced radiation dose.

METHOD AND MATERIALS
We conducted a numerical simulation study using the XCT phantom. First, we acquired two fluoroscopic images of a chest with different noise levels taking into account various physical factors such as scatter, Poisson noise, and electronic noise. We then synthesized an image by extracting and combining the ROI from low-noise image and the outer ROI from high-noise image. We applied our differential bilateral filtering scheme to the synthesized image and accurately evaluated it. For real-time image processing, the differential bilateral filtering was GPU-accelerated based on CUDA.

RESULTS
After bilateral filtering, the noise level of the outer ROI was reduced from 17% to 11%. Expected dose reduction is calculated to be about 76%.

CONCLUSION
By applying a GPU-accelerated differential bilateral filter to the ROI fluoroscopy, one can preserve or enhance the quality of low-noise ROI image and can greatly denoise outer ROI in real-time. This technique is believed to play an important role in low-dose X-ray fluoroscopic applications.

CLINICAL RELEVANCE/APPLICATION
It may help reducing imaging radiation dose during fluoroscopy for radiation therapy.

LL-PHS-TH9A Performance Comparison of Adaptive Neural Network and Support Vector Regression in Prediction of Respiratory Breathing Motion

CONCLUSION
SVR filter was superior to ANN in accuracy and it is thought to be more effective to have stable results. In addition, SVR filter was much faster, being more efficient in the actual applications. This method may be useful in predicting the patient breathing motion and enhancing the efficiency of radiation therapy.

Background
Since, patient breathing motion could move internal organ and targeted lesions determined by radiation therapy planning, it is vital to predict the patient breathing motion accurately at radiation therapy. To improve prediction algorithms of the patient breathing motion, we proposed support vector regression (SVR) algorithm to predict respiratory motion and compared the performance of the SVR algorithm to the ANN algorithm considering prediction accuracy and time latency.

LL-PHS-TH9B High Resolution Flat-Panel Detector Volumetric CT in Evaluation of Neurovascular Pathologies: Feasibility Demonstration and Preliminary Results

CONCLUSION
Our results demonstrate the unique advantages of fpVCT in evaluation of neurovascular pathologies in terms of higher spatial resolution, dynamic imaging, and superior metal artifact profile.

Background
With the advent of high resolution flat-panel volumetric CT (fpVCT), an isotropic resolution of 150μm3 can be achieved. Neurovascular and high resolution bone imaging are some potentially promising applications of fpVCT in neuroradiology. This first-in-man feasibility study compares fpVCT with MDCT in assessing neurovascular pathologies.

Disclosure Index

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