New England Chapter of AAPM  
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NEAAPM  
Peter Neurath Young Investigators Symposium

Date:    Monday, April 30th  
Time:    12:30 - 5:00 PM  
Location:  Stearns Auditorium  
Farnsworth Building  
1st Floor  
Tufts Medical Center  
171 Harrison Ave.  
Boston, MA 02111

The Peter Neurath Young Investigators Symposium was created in memory of Dr. Peter Neurath, who was Director of Medical Physics at the Tufts-New England Medical Center from 1968 to 1977. Its purpose is to encourage younger members of the medical physics community to present their research to their colleagues in the AAPM. “Young” means anyone starting out in medical physics including trainees, graduate students, post-doctoral fellows or physicists recently entered into the field. Talks are limited to approximately 15 minutes (12 minutes with 3 minutes left for questions and discussion).
Schedule of Events:

12:30  Philip Judy - History of the New England Chapter
1:00  Nolan Gagne
1:15  Huixiao Chen
1:30  Sara St. James
1:45  Yading Yuan
2:00  Mauro Testa
2:15  Joerg Rottmann
2:30  Coffee Break
3:15  Jonathan Bryant
3:30  Christopher Tien
3:45  Geoffrey Korir
4:00  Pankaj Mishra
4:15  Joost Verburg
4:30  Kesava Kalluri
4:45  Yothin Rakvongthai
5:00  Closing Remarks
5:30  Dinner at Montien (63 Stuart St., Boston, MA – See Map Below)
Methods to optimize COMS plaque loading for improved dose homogeneity and conformity

N L Gagne, D Cutright, M J Rivard

Purpose: To investigate the dosimetric optimization methods of varied intra-plaque seed strength and radionuclide choice for COMS eye plaque brachytherapy.

Methods: The COMS plaque Silastic insert arranges seeds about concentric circles (rings) of different radii. Thus, each plaque dose distribution may be considered as the superposition of its constituent rings. The MCNP5 radiation transport code was used to simulate a 16mm COMS plaque populated with $^{103}$Pd, $^{125}$I, and $^{131}$Cs sources. Each constituent source ring was then activated to determine its contribution to the total dose distribution while accounting for the dosimetric influences of inter-seed attenuation and scatter. Tumor dose distributions were generated from $>10^6$ permutations of ring weightings and radionuclides for a given apical prescription dose. These dose distributions were analyzed for target dose uniformity and conformity, and compared to that of a uniformly-loaded $^{125}$I plaque.

Results: Using $^{131}$Cs seeds in only the plaque’s outer ring yielded the most homogeneous dose distribution (+16% vs. $^{125}$I). The proximal sclera dose was 42% lower, yet center of the eye and opposite retina doses were 16% and 30% higher, respectively. Combinations with $^{103}$Pd in the plaque inner ring weighted to deliver $>98\%$ of the prescription dose yielded the most conformal dose distributions ($>24\%$ vs. $^{125}$I). Though doses to the eye center and opposite retina were $>32\%$ and $>55\%$ lower, respectively, the proximal sclera dose was $>26\%$ higher. Various combinations using only $^{103}$Pd with the outer ring contributing $>50\%$ of the prescription dose produced dose distributions both more homogeneous and more conformal than $^{125}$I. Proximal sclera, eye center, and opposite retina doses were typically 8-12\%, 11-14\%, and 38-40\% lower, respectively, than using $^{125}$I.

Conclusion: Intra-plaque radionuclide and seed strength variations produced more homogeneous and conformal dose distributions than uniformly-loaded COMS plaques. This optimization approach is generalizable to all plaque sizes and tumor dimensions.
MCO-informed VMAT planning for prostate cancer

H Chen, D L Craft, D P Giera

**Purpose:** A VMAT optimization procedure using information from Multi-Criteria Optimization of IMRT plans was developed and a treatment planning comparison was performed for prostate cancer patients.

**Methods:** IMRT plans using Multi-Criteria Optimization (MCO), 6 MV photons, 20 and 7 treatment fields were generated for 10 prostate patients in the RayStation treatment planning system (Version 2.2.13, Raysearch Laboratories, Stockholm, Sweden). The prescription dose was 7560 cGy to the prostate PTV and 5796 cGy to the seminal vesicles, using a simultaneous integrated boost technique. The resulting DVH parameters of the 20field-IMRT-MCO plan were used as initial optimization parameters for VMAT planning. The initial VMAT plan for each patient was further optimized by adjusting the optimization objectives/constraints. Final plan quality was compared using a homogeneity index (HI) and $D_{98}$ for PTV-prostate, $V_{70}$ and $V_{75}$ for anterior rectum and $V_{70}$ for bladder. Moreover, delivery efficiency of VMAT and the 7 field MCO-IMRT plans was also evaluated.

**Results:** All plans fulfilled the standard clinical objectives. The average HI of the PTV-prostate was 0.11 for VMAT, 0.13 for 20field-IMRT-MCO and 0.12 for 7field-IMRT-MCO, respectively. Average $D_{98}$ values were 7191, 7294 and 7305 cGy for VMAT, 20field-IMRT-MCO and 7field-IMRT-MCO, respectively. For organ-at-risk (OAR), $V_{70}$ and $V_{75}$ for anterior rectum and $V_{70}$ for bladder were within 3%. Analysis of delivery efficiency shows the estimated delivery time of VMAT is less than 2 minutes, while it is 7 min for 7field-IMRT-MCO.

**Conclusion:** MCO-informed VMAT optimization is a useful way to generate optimal VMAT plans. The resulting VMAT plan quality essentially matched the MCO-IMRT plan but with a shorter delivery time. Dose homogeneity of VMAT is slight superior compared to IMRT-MCO while the cold spots are slightly inferior. Furthermore, there is no clinically significant difference in OAR sparing.
Monte Carlo simulations of the dosimetric impact of ITV variations in stereotactic body radiation therapy

S St. James, J Seco, P Mishra, J H Lewis

**Purpose:** In stereotactic body radiation therapy (SBRT), large doses of radiation are delivered in few fractions, while the margins for geometric error are minimized. In these treatments, treatment volume definition is vital. If a treatment volume is poorly defined, this can result in undercoverage of the tumor if the treatment volume is smaller than required, or conversely, can result in a higher radiation dose to healthy tissue if the treatment volume is larger than required. Uncertainties in the tumor position, size and shape are accounted for by an internal treatment volume (ITV) that is derived from a pre-treatment 4DCT scan of the patient. In this work, we use patient tumor motion to create hundreds of digital phantoms to evaluate the dosimetric impact of ITV variations in a SBRT treatment of a 20 mm diameter tumor.

**Methods:** Tumor trajectories from a patient with early stage lung cancer were used to create digital phantoms. These phantoms were used to create the treatment plan and calculate the delivered radiation dose. A SBRT treatment plan was created based on a simulated 4DCT acquisition (from Day 1 tumor trajectories) and the delivered dose was simulated on (i) static phantom and (ii) dynamic phantoms representing tumor motion over 5 minutes of tumor trajectories on Day 2. The dose volume histograms for the tumor were compared.

**Results:** The dose volume histograms demonstrated differences between the static and dynamic dose calculations. The entire tumor volume was covered by 74 % of the prescription dose in the dynamic simulations, compared to 95 % in the static simulation.

**Conclusion:** This work highlights the necessity to accurately define tumor volumes in treatments where small fields and few fractions are used.
**In-Vivo Dosimetric Verification of Hypo-Fractionated Proton Radiation Therapy of the Liver with Hepatocyte-Specific Functional MRI**

Y Yuan, O C Andronesi, T Bortfeld, A Guimaraes, T Hong, J Seco

**Purpose:** To investigate the feasibility of using hepatocyte-specific functional MRI to verify proton beam range in distal regions for liver tumor treatment

**Methods:** In the treatment of liver tumors with proton beams, the dose range uncertainty in the distal region can lead to reduced dose in tumor and/or increased dose in the surrounding normal tissue. The liver function loss can be detected by employing hepatocyte-directed contrast agents such as Gadolinium ethoxy-benzyl diethylenetriamine-pentaacetate (Gd-EOB-DTPA). This change of MR signal intensity (SI) allows for a quantitative verification of dose range *in vivo*. To achieve this goal, follow-up MR images are firstly registered to the planning CT images. Then MR SI is correlated to the radiation dose at the superior/inferior penumbra dose fall-off, which includes two penumbrae in two proton beams. This SI-dose correlation is finally employed on MR images to estimate the proton end-of-range. This methodology is being evaluated on a 15-patients database, which is being collected in our institute.

**Results:** The preliminary results were based on three patients who received proton liver treatment. We observed correlations between MR SI and radiation proton dose in superior/inferior penumbra regions, with correlation coefficients ($R^2$) of 0.92, 0.99, and 0.97, respectively. By applying the SI-dose correlation to the distal region of proton beam, the mean distances from the MRI-estimated dose range to the prescribed dose range were -2.75 mm, -0.37 mm, and -2.52 mm for AP beam, and -3.60 mm, -4.39 mm and 1.52 mm for lateral beam, respectively.

**Conclusion:** The preliminary results demonstrate that the proton dose range can be verified *in vivo* to within 4.4 mm by follow-up MR images after proton liver treatment. This IRB-approved study is being extended to 15 patients with liver cancer treated by proton radiotherapy.
Assessment of the potential of a flat-panel detector to perform transmission imaging for pre-treatment range verification in proton therapy

M Testa, H Bentefour, M Rose, H Paganetti, H Lu

Purpose: To assess the potentials of a novel detector for providing a transmission image of the patient in terms of the Water Equivalent Path Length (WEPL) values and to evaluate the detector potential for real-time imaging of moving targets.

Methods: The method is based on the principle that for passively scattered proton beams the WEPL of any point located in the dose plateau of a spread-out Bragg-Peak can be derived from the time dependence of the dose rate function measured at this point. A flat-panel 2D detector array (Sun Nuclear Corporation, 249 diodes, pitch ~6 mm, 2 ms time resolution) was placed distal to a range of phantoms with varying complexities. The dose rate received by all diodes were measured as functions of time and analyzed to obtain the WEPL values. To assess the potential real-time features of this imaging technique, a Lucite cube was imaged while moving with a sinusoidal pattern with the amplitude and period comparable to a typical mobile tumor.

Results: In water tanks, millimeter accuracy in the determination of the WEPL could be achieved and the geometrical shape of wedge and sphere phantoms could be reproduced. In more complex phantoms such as a Lucite step-like compensator or Medulloblastoma patient compensators, multiple Coulomb scattering and range mixing cause a slight deterioration in the reconstruction of the WEPL. We found that tracking of a moving target in the coronal plane is potentially feasible.

Conclusion: The technique gives less than 1 cGy of dose to patients and is therefore ideal for “range-tuning” prior to treatment. For clinical applications, the beam for “tuning” will need a deeper range than the prescription and once the radiological path length to the dosimeter is determined and compared with that from planning, the proton range for the actual treatment can be adjusted.
Real-time markerless tumor tracking with MV imaging and a dynamic multi-leaf collimator (DMLC)

J Rottmann, P Keall, Y Yue, R Berbeco

**Purpose:** The implementation of a real-time adaptive therapy system. Automatic soft tissue localization (STiL) is used to drive DMLC adaptation maintaining the position of the dynamic treatment aperture relative to the tumor location during the entire breathing cycle. The STiL component utilizes electronic portal images and operates without the need for fiducial markers. The proposed system has the potential to improve treatment accuracy, dose conformity and sparing of healthy tissue.

**Methods:** The system is implemented and tested on a clinical linear accelerator featuring an electronic portal imaging device (EPID) and a DMLC system. EPID images are continuously acquired at a frame rate of 12.86 Hz. The STiL component processes the images in real-time, sending its output - the current tumor position - to the DMLC component, which moves the aperture to that position. Image transfer, tumor position calculation and DMLC motion introduce a time lag $\delta t$ between tumor position at acquisition time and at the time the treatment aperture reaches this position. We analyze this latency with a dynamic chest phantom driving a 1D sinusoidal motion (20mm superior-inferior motion range and 4.5s period). We estimate the resulting average geometric systematic error in a clinical setting by driving the phantom with several patient traces (recorded from fiducial tracking during lung SBRT).

**Results:** The individual geometric errors of the STiL and the DMLC component are each smaller than 1.0 mm. The overall system latency was found to be 210 ms. The average rms-error of 11 patients traces (172 beams) was found to be (1.8 ± 0.8) mm with this latency.

**Conclusion:** We have implemented a real-time adaptive therapy system integrating automatic soft tissue tumor localization with DMLC adaptation of the treatment aperture. The functionality of the combined system was tested successfully and the systemic latency and resulting rms error measured.

**Conflict of Interest:** Varian Medical Systems Inc., NCI grant CA93626
Visualizing Lung Tumor Target Volume Contours on EPID Cine Mode Images

J H Bryant, R I Berbeco

Purpose: While real time imaging of treatment through an electronic portal imaging device (EPID) is a powerful tool to monitor treatment, limited field of view and lower contrast from an MV beam can make assessment difficult for physicians. This work will develops a method to register and project contour outlines for the internal target volume (ITV) and planning target volume (PTV) of lung tumor cases onto cine mode EPID images to help physicians in interpretation during treatment.

Methods: A sequence of EPID images, acquired during treatment, was registered to treatment planning computed tomography (CT) by machine geometry and patient setup with cone-beam computed tomography (CBCT). The planning CT was converted from Hounsfield scale to electron density by calibration curves of our CT simulator and digitally reconstructed radiographs (DRRs) were produced to match the EPID geometry, pixel for pixel. ITV and PTV structures as defined on the planning CT were then projected onto the DRRs. The DRRs were registered to the EPID images using cross correlation of a single template defined within the treatment aperture of each image. Once registered, the contours from the DRR were transferred to the EPID.

Results: We were able to successfully register electron density based DRRs to EPID images and display the projected target volumes. Without motion, geometric registration and CBCT guided patient setup up were sufficient to register the contours. Shifts of several millimeters calculated by normalized cross correlations compensated for breathing motion. We expect the DRR/EPID registration to be an important step when looking at cases with substantial tumor movement.

Conclusion: The visualization of target volumes provides a tool for physicians to interpret EPID images and assess treatment, especially in cases with tumor movement. The methods developed will serve as the basis for a clinical tool providing real time contours.
Impact of fractionation scheme and tracking method on CyberKnife imaging dose

C J Tien, S Lee, B H Curran, E S Sternick

Purpose: CyberKnife® stereotactic radiosurgery (SRS) systems employ image guidance during delivery for real-time target localization. This investigation evaluated the effect of fractionation and tracking method on CyberKnife SRS imaging dose.

Methods: Imaging information was retrospectively collected for 427 CyberKnife SRS patients from two institutions using different fractionation and tracking methodologies. This difference arises from physician preference regarding lesion location, size and type. Institution A predominantly uses single-fraction skull-based tracking while Institution B uses three fractions with either skull-based or spine-based tracking.

Results: Each image delivered 1.231 mGy entrance skin exposure (ESE). Changing from one-fraction to three-fraction treatments resulted in 350%-400% increased median number of images taken (MNIT). Changing from skull-based to spine-based tracking resulted in a further 150% increased MNIT. While the relative numbers increased by the same amount, there was a two-fold inter-institutional difference in absolute numbers which was due to different imaging intervals. Limited sampling for fiducial-based and lung-based tracking showed MNIT of 1200 (1477 mGy-ESE) and 2600 (3200 mGy-ESE), respectively.

Conclusion: By changing from one- to three-fraction treatments and changing from skull-based to spine-based tracking, the ESE from imaging can increase 1200%. While relatively small compared with prescription doses, imaging does contribute to the overall patient dose. In addition to documentation, physicists should have an estimate of absolute ESE – based upon fractionation and tracking – in order to anticipate potential radiation effects of this imaging dose.
Assessment of Patient Dose in Fluoroscopically Guided Medical Procedures

G K Korir, J S Wambani, M M Kidali, I K Korir

Purpose: To assess the level of patient dose involved in fluoroscopy and interventional procedures, compare with the international diagnostic reference levels and establish the initial institutional diagnostic reference levels.

Methods: A survey was undertaken for fluoroscopically guided procedures using the medical records kept at the referral, teaching and research hospital in Kenya. The peak skin dose, kerma area product and fluoroscopy time were measured for six hundred children (26%) and adult (74%) patients undergoing routine radiological procedures in an equipment installed with integrated dose measuring system.

Results: Majority of the examinations considered in the study showed patient doses above the available diagnostic reference levels, indicated wide patient dose variations per examination and 5% of the measured cumulative skin dose for the interventional procedures approached the threshold dose limit implicated in causing deterministic effects like skin injuries.

Conclusion: The cumulative skin dose data along with kerma area product readings should be routinely recorded to enhance radiation dose management and advising of patients when radiation dose with potential deterministic effects are measured. There is need to adopt optimization of patient protection through operator training, use of institutional diagnostic reference levels, development of guidelines for accreditation and credentialing of specialists.
Fluoroscopic 3D images based on 2D treatment images using a realistic modified XCAT phantom

P Mishra, R Li, S St. James, R Mak, Y Yue, R I Berbeco, J H Lewis

**Purpose:** To simulate the process of generating fluoroscopic 3D treatment images from 4DCT and individual 2D x-ray projections using a realistic patient data-based modified XCAT phantom.

**Methods:** The process consists of the following steps:

**4DCT data based on modified XCAT:** We developed a modified XCAT digital phantom based on measured patient tumor trajectories. To generate an XCAT phantom incorporating the measured tumor trajectories and synchronized realistic anatomic motion, we adaptively calculate the chest wall and diaphragm motion based on a specific tumor motion.

**Patient-specific PCA lung-motion model:** To build a patient-specific lung-motion model a set of displacement vector fields (DVFs) corresponding to different phases of 4DCT are generated. To compactly represent these DVFs we use Principal Component Analysis (PCA) as it captures salient characteristic of the DVFs in a 2 to 3 eigenvectors.

**Fluoroscopic 3D image generation:** This is achieved via a cost function in which a projection matrix P connects the 3D reference image to the single projection image x. This cost function iteratively updates the PCA coefficients and DVFs to approximate the given projection image in a mean-squared sense.

**Results:** We constructed a PCA lung motion model at a resolution of (2, 2, 2.5) mm in (x, y, z) respectively. The error metric used was the average of the absolute distance each pixel in a reconstructed image moves compared to the ground truth image (Erecons) versus the same measure for the reference image (Eref). The mean of Erecons is 0.079 mm and Eref is 0.1665 mm with standard deviation 0.0060 and 0.0678 mm respectively.

**Conclusion:** We developed a methodology to simulate the process of generating fluoroscopic 3D treatment images based on prior information in the 4DCT and single x-ray projections measured during treatment.
CT metal artifact reduction method correcting for beam hardening and missing projections

J Verburg, J Seco

Purpose: To develop a computed tomography (CT) metal artifact reduction method for a wide spectrum of clinical implant materials.

Methods: The proposed CT metal artifact reduction method combines two algorithms. A physics correction algorithm was designed that performs a first-order correction of the beam hardening caused by low-Z implants such as titanium. In the case of high-Z implants (amalgam, platinum, gold), which result in a near complete x-ray attenuation, the missing projection values were replaced with estimates obtained through a regularized iterative image reconstruction. The algorithms were combined if both types of implants were present. To assess the performance of the proposed method, a retrospective study was performed on the original projection data of 4 patient scans. 10 radiation oncologists ranked the quality of the original and artifact reduced images. The proposed method was also compared to the conventional approach of projection interpolation.

Results: Metal artifacts caused by titanium orthopedic hardware, dental fillings, platinum coiling and a gold eye weight were significantly reduced. For the scans that included low-Z implants, the proposed method was ranked as the best method in 90% of the reviews. It was ranked superior to the original reconstruction ($p = 0.0008$) and conventional projection interpolation ($p < 0.0001$). All reviewers ranked the method first for the scans with high-Z implants, and better as compared to the original reconstruction ($p < 0.0001$) and projection interpolation ($p = 0.004$). Unlike projection interpolation, the proposed method did not cause a loss in spatial resolution near the implants.

Conclusion: Effective reduction of CT metal artifacts was achieved by combining a beam hardening correction for projections through low-Z implant materials and an iterative projection replacement algorithm for high-Z implants.
Comparing human observer performance in detecting microcalcifications with energy weighting and photon counting breast CT

K S Kalluri, M Mahd, S J Glick

Purpose: To compare human observer performance in detecting microcalcifications using energy weighting and photon counting breast CT.

Methods: Reconstructed images were generated using computed tomography breast imaging (CTBI) simulation software by inputting a numerical breast phantom (with 240 μm microcalcifications inserted). The simulation study involved modeling two different x-ray detectors (with ideal operation), the first was a cesium iodide based energy integrating detector (EID) and the second was a cadmium zinc telluride based photon counting detector (PCD with energy weighting).

The methods compared were:
1. EID with aluminum filter (EID$_{Al}$)
2. EID with cerium filter (EID$_{Ce}$)
3. PCD with projection based weighting 1keV energy windows (PC-PB$_{1keV}$)
4. PCD with projection based weighting with 3 energy bins (PC-PB$_{3EW}$)
5. PCD with image based weighting with 3 energy bins (PC-IB$_{3EW}$)

A human observer study was conducted with three medical physicists, where the observer’s task was identify the presence of microcalcifications from 150 suggested locations in 6 reconstructed images (for each method) with a detection confidence rating scale of 1-4. ROC was used to analyze the human observer confidence data for the different imaging methods.

Results: The average area under the ROC curve (AUC$_{Avg}$) for the EID$_{Al}$, EID$_{Ce}$, PC-PB$_{1keV}$, PC-PB$_{3EW}$, PC-IB$_{3EW}$ (for the three human observers) were .67, .74, .91, .89, .86 respectively.

Conclusion: The AUC$_{Avg}$ for the PC-PB & PC-IB approach is substantially higher as compared to EID based imaging. As compared to the AUC$_{Avg}$ for the EID$_{Al}$ curve, the improvement for the EID$_{Ce}$, PC-PB$_{1keV}$, PC-PB$_{3EW}$, PC-IB$_{3EW}$ were 7%, 23%, 22%, 19% respectively.
A Preconditioned Conjugate Gradient Method for Direct Reconstruction of PET Parametric Images

Y Rakvongthai, J Ouyang, Q Li, B Guerin, N M Alpert, G El Fakhri

**Purpose:** We developed a new approach based on the PCG algorithm to directly reconstruct PET parametric images from sinograms and yield more precise and accurate estimation than what can be achieved with indirect approaches (curve fitting of reconstructed images).

**Methods:** We generated nine PET noise realizations of an NCAT torso phantom (including heart, lungs, liver, and soft-tissue compartments). Using realistic parameters obtained from previously reported dynamic myocardial blood flow studies, time activity curves of all organs were simulated based on a 1-compartment kinetic model. To estimate parameters, we optimized a cost function which consists of the Poisson log-likelihood and a spatial regularization terms using the PCG, where the elements of the diagonal preconditioner are the ratio of the parameter and the sensitivity of the radioactivity associated with parameter. To address the local minima problem, the initial guesses for the iterative algorithm were set to those obtained from the indirect approach where we reconstructed the dynamic images frame-by-frame using OSEM, and curve-fit them with the kinetic model.

**Results:** The PCG algorithm with the proposed preconditioner converged significantly faster than CG in optimizing the cost function. Moreover, for the same bias, our PCG approach yielded a significant reduction in standard deviation of $K_1$ compared to the indirect approach ranging from 42% in the anterior wall to 32% in the lateral wall.

**Conclusion:** We developed a new PCG algorithm and demonstrated that our proposed preconditioner accelerates significantly the direct PET parametric reconstruction yielding substantially reduced variance, for the same bias, in kinetic parameter estimation as compared to indirect methods.

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