WesCan 20/20: Maintaining Clarity in a Complex Future Abstracts

Note: Abstracts are organized in alphabetical order by last name of the presenter (name underlined)

Keynote Presenters

- **Gillan, Caitlin** - Square Peg, Round Hole: Conceptualizing AI's Disruption to Practice
- **Otto, Karl** - Deep Learning: Important Concepts and Application to Automatic Segmentation of Medical Images

Scientific Session Presenters

- **Anjomani, Zahra** - A Robust and clinically relevant skin toxicity indicator in Permanent Breast Seed Implant brachytherapy
- **Badragan, Iulian** - A Study in Least Squares - The Mysterious Case of the Gamma Rate Sweet Spot
- **Baldwin, Lesley** - Commissioning of a patient-specific 3D printed bolus program for clinical radiotherapy at the Cross Cancer Institute
- **Barta, Radim** - How to build an RF-coil for the Rotating B0 Linac-MR
- **Basran, Parminder** - Evaluation of radiomic feature selection and classification algorithms in microCT of racehorse bones
- **Bergman, Alanah** - First Trajectory-Based VMAT Clinical Delivery in Canada: Dynamic Wave Arc (DWA)
- **Bromma, Kyle** - Determining the effect of nano-based therapeutics in cancer vs normal cells
- **Carpentier, Emilie** - A novel method for calculating dose on different breathing phases during dynamic tumour tracking on the VERO4DRT linear accelerator
- **Crewson, Cody** - Leapfrogging Software. A story of skipping Aria RO 13
- **Dunning, Chelsea** - Photon-counting computed tomography of lanthanide contrast agents with a high-flux 330um cadmium zinc telluride (CZT) detector
- **Duzenli, Cheryl** - CARA Breast Positioning: Study updates
- **Earnshaw, Kelly** - Improving bladder and bowel variability during prostate radiotherapy using a standard protocol and daily patient feedback.
- **Gaffney, Helene and Sondhi, Ankit** - Planning comparison of field in field tangent breast radiation therapy using Varian Eclipse treatment planning system vs. EZFluence, an automated planning software: Planning time and quality
- **Hart, Alexander** - FDG Dose Reduction Based on NEMA PET Phantom study
- **Larocque, Matthew** - Conformal Ocular Brachytherapy in Alberta
- **Lawyer, Kim** - Squint – Efficient DVH-based plan comparison and evaluation using ESAPI
- **Mann, Thomas** - No more "spherical" patients: Path to improved radiosurgery treatment based on optimized beam angles

- **Matthews, Quinn** - Evidence-based PTV margin reduction for modern lung SABR using deformable registration
- **Mendez, Claudia** - eFLASH Radiotherapy at BC Cancer – Vancouver
- **Mestrovic, Tony** - Comparing different methods of assessing the safety of complex treatment plans with dynamic tumour tracking on the Vero4DRT linear accelerator
- **Popescu, Carmen** - The Vancouver Island experience in prone breast radiotherapy - moving forward
- **Quirk, Sarah** - A programmatic approach to automation in radiotherapy at the TBCC
- **Richtsmeier, Devon** - Parameter optimization for multi-contrast imaging using photon-counting CT
- **Rodriguez, Manuel** - Novel User-friendly Software to Streamline QA of HDR Brachytherapy Plan
- **Shaw, Conor** - Timeline of Symptoms Leading to the Discovery of Damage to a Varian Clinac Target
- **Small, Valerie** - ALIGN RT – Surface guided radiation therapy as used at VIC
- **Smela, Nathan** - 3D printing silicone bolus
- **Ta, Don** – Development of a Phantom Incorporating Simultaneous Cardiac and Respiratory Motions
- **Thomas, Steven** - Susceptibility Induced MRI Geometric Distortion Prediction
- **Thomas, Steven** - Titanium Susceptibility Measurements of Spine Hardware.

Square Peg, Round Hole: Conceptualizing AI's Disruption to Practice
Caitlin Gillan

Artificial intelligence (AI) in healthcare will require consideration of employment, training, education, and professional regulation. Recognizing that we are best served by taking a proactive approach to considering the nature and potential scope of AI, both in its benefit to our patients and in its impact on healthcare and those who practice it, it is important that we equip ourselves to engage in the relevant conversations. In radiation medicine we find ourselves at a crossroads, where our professions need to decide how they envision the impact of AI in our practice, and how we can collaboratively define appropriate AI-enabled care alongside society, industry, and other stakeholders.

Gains in quality and efficiency in radiation medicine practice will require new workflows, skills and even models of care for all relevant professional groups. As we work to separate the reality from the hype, the cautious optimism from the fearmongering, and the human opportunities from the expansion of technology, we can begin to prepare for the future. Doing so will require an acknowledgement that we are not simply replacing humans with AI within the existing model of radiation medicine practice, but rather fundamentally disrupting practice by augmenting human abilities.

This session will highlight the professional, ethical, regulative, and educational considerations around AI that should be as equally emphasized as the clinical and technical advancements in order to ensure responsible integration while maximizing potential. Technology is only as good as the people and system equipped to support it.

Caitlin Gillan, MRT(T) BSc MEd FCAMRT
Caitlin is a radiation therapist by training, having practiced for 12 years at the Princess Margaret Cancer Centre in Toronto. Since 2019, she has served as the Manager of Education and Practice for the Joint Department of Medical Imaging at Sinai Health, University Health Network, and Women's College Hospital. She is currently immersed in her PhD at the University of Toronto, considering how medical imaging and radiation therapy professions are preparing for artificial intelligence.

Deep Learning: Important Concepts and Application to Automatic Segmentation of Medical Images
Dr. Karl Otto

Deep Learning (DL) has shown promise for advancing a wide range of different fields. Self-driving cars, drug discovery, robotics, virtual assistants and more. A key ingredient for success with Deep Learning is large amounts of labeled data. Radiation therapy is a promising area for applying DL because each patient has many forms of data associated with them including images, dose distributions, treatment delivery parameters, consultation notes etc. Deep learning has been applied to natural image classification and object detection since it first showed promise in 2012. In our work we explore current and emerging DL methods that are applicable to RT images. In particular, we have developed a comprehensive platform for automatic segmentation (contouring) of CT and MRI images (Limbus Contour).

Limbus Contour uses a multi-layer "U-net" deep neural network. The U-net architecture accepts a series of CT or MRI images as input. At each network layer the input from the previous layer is processed and rescaled by applying multichannel convolution operations. Each layer forms a deeper abstraction of the possible shape and location of the structure being contoured. These abstractions are then deconvolved and expanded in another series of layers to build a new image where each pixel represents the probability that the structure exists at that location. The DNNs were trained for a variety of structures using several expert contoured scans as reference. Structures included all typical head and neck, CNS, lung and pelvis healthy tissue structures used in RT planning. A separate set of scans was used to evaluate the accuracy of the DNN contours.

DL based auto-segmentation can reduce contouring time dramatically, by 90% in most cases. Auto-segmented contours closely match RO contours and fall within inter-observer variability, particularly for OARs. Auto-segmented CTVs can serve as a starting point for subsequent manual edits.

Learning Objectives:
1. Understand the basic concepts of deep learning and how this rapidly evolving technology can be applied to automatic contouring of medical images.
2. Learn how state of the art deep learning based contours compare to expert contours.
3. Understand how deep learning methods can be successfully integrated into the clinical environment.

Dr. Karl Otto, PhD FCCPM MCCPM
Karl Otto is an Adjunct Professor in the Department of Physics and Astronomy at the University of British Columbia. His research includes Volumetric Modulated Arc Therapy (VMAT), 4D VMAT planning and real-time interactive planning methods for general and adaptive RT. The planning algorithms developed by Dr. Otto are now included in the commercial RapidArc platform offered by Varian Medical Systems. RapidArc is now used in over 1000 centers worldwide. Dr. Otto received the British Columbia Young Innovator Award and the Canadian Organization of Medical Physics his development of VMAT. He also received the Sylvia Fedoruk award and Publication Impact Prize from the Canadian Organization of Medical Physics for this contribution. More recently Dr Otto joined Limbus AI to pursue applications of Deep Learning and Artificial Intelligence for RT planning and treatment.

A robust and clinically relevant skin toxicity indicator in Permanent Breast Seed Implant brachytherapy

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Purpose: To establish skin dose-outcome relationships using a reliable metric in Permanent Breast Seed Implant (PBSI).

Methods: 67 consecutive patients who underwent PBSI at our institution were included. Skin doses were calculated using two skin dose indices: maximum point dose to the skin surface, D_{max}, and $D_{0.2cc}$ for a 2mm internal skin rind (a surrogate to the dose to $1cm^2$ area of skin) from CT based post-operative treatment plans. Toxicity data were extracted from patients' charts and photographs. Skin toxicities included were erythema, pigment change, desquamation and ulceration for acute skin reactions (<6 months) and telangiectasia for late skin toxicity (with at least 3 years follow-up). Acute toxicities were scored following the National Cancer Institute Common Toxicity Criteria for Adverse Events v5.0. The associations between skin dose and skin toxicity were investigated using the analysis of variance and the predictive performance of skin dose measures was evaluated using receiver operating characteristic curves.

Results: For acute reactions, 49.3% of patients had Grade 1, 4.5% Grade 2 and 1.5% Grade 3 toxicity. For telangiectasia at 3 years, the majority of occurrences (25%) were very minor and minimally apparent telangiectasia. Moderate but asymptomatic telangiectasia was observed in 9.1% of cases. Both metrics were significantly associated with occurrence of acute toxicity and telangiectasia at 3 years ($P<0.01$). The predictive values for D_{max} and $D_{0.2cc}$ were 0.779 and 0.763, respectively, ($P<0.0001$) for acute skin toxicity and 0.786 and 0.810 for telangiectasia ($P<0.0002$). Extreme dose outliers (up to 878Gy) and a high variability were observed for D_{max} but not for $D_{0.2cc}$, illustrating the superior reliability of $D_{0.2cc}$.

Conclusion: $D_{0.2cc}$, as an alternate skin dose measure to D_{max}, is a robust metric for measuring skin dose that is simple to calculate, yet is clinically relevant and not prone to inaccuracies inherent to point dose measurement.

A Study in Least Squares - The Mysterious Case of the Gamma Rate Sweet Spot

Badragan I, Poon J, Badragan G

Purpose: This work touches on some fundamental aspects of using detector arrays for regular QA and plan-specific dosimetry. While building on earlier experimental study findings such as the existence of gamma passing rate sweet spots and their plan dependence, it strongly focuses on the mathematical modeling side and is able to draw general conclusions about all possible detector arrays on the market. Along the way, this study arrives at some conclusions regarding the correct data interpretation and the best use of detector arrays in clinical practice.

Methods: We have employed a number of mathematical and computer programming tools during this study, such as the principle of maximum likelihood with its total least square derivative, and the R statistical programming language. Two separate models have been considered, and tested by numerical simulation against observed data, with the winner being rooted in the least square approach.

Results: The mathematical & computational models developed were able to reproduce the general behavior of the experimental data and also resulted in valuable insights into the fundamental causes for the observed plan dependence of the gamma sweet spots. This in turn, enhanced our understanding of the data we get in actual practice and suggested ways to optimize our plan-specific QA process.

Conclusion: Our results demonstrate that every dose array measurement, regardless of its geometry is subject to a certain amount of uncertainty emerging purely from the existence of gamma rate sweet spots and their plan dependence. Many of the occasional lower pass rates observed, have nothing to do with a faulty plan or delivery. Although the uncertainty range may be vendor specific, the general behaviour of dose arrays remains the same, which results in some interesting practical consequences.

Commissioning of a patient-specific 3D printed bolus program for clinical radiotherapy at the Cross Cancer Institute

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Purpose: To detail the commissioning and early clinical experience with patient-specific 3D printed bolus for radiotherapy at the Cross Cancer Institute.

Methods: Prior to routine clinical use, we established standard print parameters with our Fusion3 F400-S 3D printer by evaluating printed test material's dosimetric equivalency against known materials. Once satisfied with the 3D print quality, we proceeded to print patient- specific boluses for use in radiation therapy. Our clinical workflow begins with a CT scan of the patient and digital bolus design within Eclipse. The bolus structure is exported via an Eclipse API script, which converts the structure into a meshed .stl file, which is further refined using Meshmixer. Each patient bolus is inspected via a CT scan to determine its mean HU value and to ensure the absence of internal defects. Bolus fit is assessed via CBCT on the first day of treatment and OSLs were used to verify surface dose for the first twenty patients.

Results: Results from the first twenty patients show consistent integrity and material density with mean HU values of 111 _ 9 HU (in air) and 110 _ 7 HU (in water). CBCT assessment of fit has shown good conformality to complex surface contours. When a comparison was available between 3D printed bolus and wax, 3D printed boluses appeared to have superior conformality. OSL dosimetry found that doses delivered were within 3.3 % of planned doses in all cases.

Conclusion: 3D printed boluses can be used to achieve predictable surface doses under complex geometry. The process is simple, efficient, and reproducible.

How to build an RF-coil for the Rotating B_0 Linac-MR

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Purpose: To outline the process by which a MRI detector developer moves from desired imaging application, through coil design, to coil construction, and finally coil testing. The process is demonstrated on the development of a coil for a rotating B_0 Linac-MR.

Methods: The Alberta Linac-MR is a 0.5 T MRI combined with a 6 MV linear accelerator (linac). The B_0 magnet is mounted on the same gantry as the linac. RF (radio frequency) coils were designed and constructed to meet the unique requirements of this system: minimal interaction with the beam and gantry angle independent imaging. An out of beam RF-coil array consisting of two butterfly coils and one loop coil was built and tested. A vector network analyzer was used to measure coil properties, tune the coils, and match each element. Gradient echo images were acquired on the Alberta 0.5 T Linac-MR with the gantry (hence B_0) at 0, 45 and 90 degrees. At each angle individual channel images were combined using weighted root sum of squares (wRSS) combination and signal to noise (SNR) was calculated.

The tuning and measurement of quality factor (Q) for a loop coil will be demonstrated during the presentation.

Results: Images acquired with the three-channel array have uniform SNR at all gantry angles. As expected, the two butterfly coils complement each other, allowing the array to maintain about the same SNR for all angles.

Conclusion: The three-channel array demonstrates how careful design, construction, and testing allows an RF-coil developer to meet unique requirements a given application. In this case, achieving gantry angle independent imaging that is useful for the rotating B_0 Linac-MR. Description of the development of the array along with the live demonstration will give insight into the use of MRI detectors and teach the basics of how to build an RF-coil.

Evaluation of radiomic feature selection and classification algorithms in microCT of racehorse bones

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Purpose: Radiomics is a method that extracts a large number of features from medical images, which can be used for predictive modeling (Machine Learning). Two challenges with predictive modelling via radiomics is a) feature selection and; b) choosing an appropriate classification algorithm. The purpose of this work is to investigate a wide array of statistical tests and classifications methods for a specific use-case.

Methods: 64 sesamoid bones from 16 racehorse forelegs were scanned with microCT, where 8 horses suffered catastrophic injury. Radiomic features were extracted from intact, unfractured bones. Image biomarkers were calculated using an Image Biomarker Standardization Initiative package. A variety of statistic tests (e.g., Students t-test, Fisher Score, Relief Score, Maximum Entropy Minimization) were computed and a predictive model was generated with a variety of classification algorithms (e.g., Logistic Regression, Naïve Bayes, Support Vector Machines, Random Forest). The accuracy and Area Under the Curve (AUC) were computed for each combination of feature selection method and classifier. Accuracy and AUC values were averaged over feature selection methods and classification algorithms, and the sum of ranks provided a final score (lowest score=highest overall AUC and accuracy).

Results: For feature selection, the Wilcoxon test ranked highest, followed by T-test and Relief Score, whereas Fisher score performed poorly. For classifiers, Cubic Support Vector Machines and Random Forest ranked highest whereas Logistic Regression and some Ensemble methods performed poorly. These findings agree with works of radiomics of CTs in cancer patients.

Conclusions: Based on this type of imaging modality (microCT) and specific clinical application (assessing fracture risk), Wilcoxon or Relief Score feature selection methods in combination certain types of Support Vector Machines or Random Forest provide stable and accurate predictions. Quantitative evaluation of feature selection and classifications ensures that the predictive model is as robust as possible.

First Trajectory-Based VMAT Clinical Delivery in Canada: Dynamic Wave Arc (DWA)

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Purpose: To report on the first clinical trajectory-based volumetric modulated arc therapy (VMAT) in Canada: Dynamic Wave Arc (DWA).

Methods: DWA is a clinical module on the Brainlab Vero4DRT 6MV radiotherapy accelerator. It delivers VMAT arcs with simultaneous gantry and floor-ring rotations, resulting in 'baseball stitch'-type trajectories. A team of medical physicists, physics assistants, radiation therapists, radiotherapy technology service technicians and radiation oncologists worked together to commission and clinically implement the 'dynamic wave arc' functionality. The treatment planning system (TPS) was RaySearch RayStation (v7) utilizing the collapsed cone convolution algorithm. Closed loop measurements were performed with an ArcCheck cylindrical diode array (SunNuclear) and 0.6cc Farmer-type ion chamber. Planning strategies and clinical treatment workflows were created. A dedicated, in-house beam-trajectory optimizer and collision detection algorithm for planning was created. A Monte Carlo Vero model was also developed to complement patient-specific QA measurements.

Results: The first patient (pelvic bone) to receive DWA in Canada was successfully treated in October 2019 using 2x DWA arcs (35 Gy). Pre-treatment QA demonstrated an ion chamber-vs-TPS dose agreement to within 1.4%. Measured-vs-TPS calculated ArcCheck 2D planar dose differences were assessed with the gamma factor; 3%/3mm and 2%/2mm pass rate (30% threshold) was 100% and 98%, respectively. 3D Monte Carlo-vs-TPS doses calculated on a uniform cylindrical phantom were compared with the gamma factor; 3%/3mm MC-TPS 3D gamma was 98.3%. The collision-detection and trajectory optimizer applications were useful tools for planning. A "Day 1" dry-run with the patient on the couch is still recommended as the dynamic floor-ring motions increase collision potential. Delivery time for 2-arcs (7 Gy/fraction) was 4 min.

Conclusion: Dynamic Wave Arc is an innovative technique that is elegant, efficient and safe. This is the first report of a clinical trajectory-VMAT type delivery in Canada. https://youtu.be/ePpIcnm86kQ

Determining the effect of nano-based therapeutics in cancer vs normal cells

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Purpose: One of the major issues in cancer radiotherapy (RT) is the normal tissue toxicity. Introduction of radiation dose enhancers such as gold nanoparticles (GNPs) into cancer cells has been tested as a promising approach to enhance the dose while minimizing the damage to surrounding healthy tissue. However, tumor microenvironment consists of not only cancer cells but also normal fibroblast cells (NFs), cancer associated fibroblasts (CAFs) in addition to immune cells and vasculature. The goal of this study was to understand the extent of GNP uptake and retention in cells within the tumor matrix for successful application of GNPs into current RT.

Methods: We used HeLa as our model cancer cell line. For evaluation of the GNP uptake, HeLa, FBs, and CAFs were incubated with GNPs of 15 nm diameter at 0.2 nM concentration over a period of 24 hours. For studying the retention, cells were incubated with GNP and left in fresh media over a period of 24 hours. A photon-based radiation dose of 2 Gy was given using a clinical linear accelerator to assess the RT in the presence and absence of GNPs.

Results: Uptake of GNPs was much higher in HeLa and CAFs as compared normal FBs. A radiation dose of 2 Gy lowered the survival and proliferation of all the cell lines. However, the addition of gold caused an additional initial decrease in survival over time, which, when combined with fractionation, could lead to major benefits in future therapeutic outcomes.

Conclusion: Higher uptake of GNPs in cancer cells and CAFs would allow much needed local dose enhancement within tumor tissue

A novel method for calculating dose on different breathing phases during dynamic tumour tracking on the Vero4DRT linear accelerator

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Purpose: The Vero can perform real-time dynamic tumour tracking (DTT) with a gimbal-mounted linac head. No treatment planning systems (TPS) model this gimbal motion, so DTT plans are evaluated on a single respiratory phase (eg. exhale) despite the beam's panning/tilting motion. Here we discuss our methods for re-calculating the dose distribution on a different breathing phase by properly modelling the beam's panning/tilting during DTT.

Methods: A script was developed in-house to transfer a step-and-shoot intensity modulated radiotherapy (sIMRT) plan made on one breathing phase (eg. exhale) to another (eg. inhale). The script alters the gantry, ring and collimator angle, and calculates an isocenter shift, for each beam to mimic its path through the body during tracking. To test this script, we created a sIMRT plan on a cylindrical phantom CT. The target was moved 1.2-2.2 cm in one, two and three dimensions between the "exhale" and "inhale" phases and the script created a new plan for each case. We then examined dosimetric differences and the beam's eye view (BEV) for each beam in the new and original plans.

Results: During testing, the mean dose to the target in the original plan was 4573 cGy, and the new plan on the "inhale" CT for 1D, 2D, and 3D motion produced mean doses of 4572 cGy, 4612 cGy, and 4615 cGy, respectively. The BEV shows the target is kept in the centre of the aperture with the same orientation as the original plan.

Conclusions: Our script successfully re-calculates the dose distribution of a sIMRT plan optimized on a single breathing phase (eg. exhale) on another breathing phase (eg. inhale) while properly modelling the beam's altered path from panning and tilting during DTT. This script can ensure a patient will not exceed dose constraints on other breathing phases if they are having DTT.

Leapfrogging Software: A story of skipping Aria RO 13

Crewson, Cody; Glass, L; Alexander, A; Hastings, J; Garratt, K; Priddell, S;

Saskatchewan Cancer Agency (SCA)

Purpose: To develop and share the workflow, performance, high availability, and disaster recovery strategies of a new Aria 15 environment without the experience of Aria 13.

Methods: A survey of best practices, current technologies, and future roadmaps were used to judge a testing strategy for failover and performance analysis. Plans were complicated by our infrastructure requirements, being a single database controlling 8 linear accelerators over 2 medical facilities. This included failover and in situ testing of the development environment which was confirmed with additional testing as part of commissioning the new clinical environment. Additional strategies and testing were required for Eclipse commissioning and backup workflows in the event of system outages. Preliminary testing methodologies of the new GPGPU functionality will also be shared.

Results: The use of Active Directory, and failover/disaster recovery tools that are part of our existing infrastructure have lead to significant IT support savings. This has created opportunities for more unified and frequent testing of backup infrastructure. Further the improved workflow and increased performance have yielded gains to our clinical teams.

Conclusion: Aria 15 simplified and unified a significant portion of our workflow but the integration with Active directory and introduction of new installation strategies for the Eclipse calculation servers has lead to a significant number of lessons learned and future changes.

Photon-counting computed tomography of lanthanide contrast agents with a high-flux 330um cadmium zinc telluride (CZT) detector

Chelsea Dunning

Purpose: To simultaneously image iodine and novel lanthanide contrast agents with similar atomic number (Z) in a small animal phantom using weighted K-edge subtraction on a table-top photon-counting computed tomography (PCCT) imaging system.

Methods: The table-top PCCT imaging system included a diagnostic x-ray tube, phantom rotation stage, a translation stage to enable detector motion and a 330μm-pitch high-flux cadmium zinc telluride (CZT) photon-counting detector of 8mm x 24mm in size. The detector's six energy bins were set to match the contrast agent K-edges. Four 3D-printed 3cm-diameter cylindrical phantoms each contained seven 6mm-diameter vials with water and 0.5% - 5% concentration solutions of various contrast agents, including lanthanum (Z=57), gadolinium (Z=64), and lutetium (Z=71) in one phantom and iodine (Z=53), gadolinium, and holmium (Z=67) in the other phantom. 120kVp, 1mm Al-filtered cone beam x-rays at 1mA imaged each phantom using 180 rotation steps to a mean imaging dose of 110mGy. Six energy-binned CT images were reconstructed using the Feldkamp-David-Kress (FDK) algorithm, from which weighted K-edge images were produced. The root-mean-square error (RMSE) was used to evaluate the reconstruction accuracy and cross-contamination of each vial for the K-edge images.

Results: All contrast agents were well separated. The RMSE of each contrast agent in their K-edge images were all < 0.29% and 0.51% for the 0.5% and 5% solutions, respectively. Minimal cross-contamination in each K-edge image was seen, with the highest RMSE outlier at 0.27% and most RMSE values < 0.10% in vials containing no contrast. Excellent signal linearity was seen for all contrast agents with $R2 > 0.996$.

Conclusion: This work demonstrated the first multiplexed PCCT imaging of three similar-Z contrast agents ($\Delta Z=3$) in one scan. In the clinic, multiplexed PCCT will potentially enable visualization of different processes in a disease pathway tagged with novel contrast agents in a single scan.

CARA Breast Positioning: Study updates

Cheryl Duzenli

Purpose: Breast positioning in RT continues to be a challenge for patients with high BMI and/or large pendulous breasts. Prone breast positioning is helpful for some patients, but the majority of patients still require supine positioning. To assist with supine positioning of larger ptotic breasts which tend to fall inferiorly, laterally, or both, our team has designed, built and tested a carbon–fibre breast support device which is indexed and adjustable for individual patients.

Methods: Our testing to date consists of a 9 participant design study, a 10 patient treatment planning study and a 20 patient treatment pilot study including in-vivo dosimetry to assess skin dose. Patients in the planning and treatment study were planned with and without the CARA support for comparison.

Results: These studies indicate promising results with the more anterior breast position achievable using the CARA versus the current standard of care. IMF skin folds can be eliminated and lateral beam entry points move anteriorly, such that less lung need be included in the tangential field. Breast separation is reduced using the CARA resulting in more homogeneous dose distributions. Significant reductions in $V20Gy_{lung}$ and $V105\%_{Body}$ are seen in 70% of patients to date. 8 of the 20 patients in the treatment pilot study were left breast patients treated using DIBH technique. The in-vivo skin dose study has quantified buildup and scatter dose contributions from the carbon-fibre device.

Conclusion: These findings have led to a slight revision to the device prototype and informed the protocol design for a randomized trial being conducted at BC Cancer to evaluate the incidence of moist desquamation in whole breast RT for CARA positioning versus standard of care. Use of CARA for partial breast irradiation raises interesting possibilities and we seek to investigate this in the upcoming year.

Improving bladder and bowel variability during prostate radiotherapy using a standard protocol and daily patient feedback.

Kelly Earnshaw

Purpose: Variability in bladder and bowel filling during prostate radiotherapy can result in under dosing of the target and/or increased dose to the organs at risk (OAR). At BC Cancer-Victoria, a new bladder and bowel preparation protocol (BBPP) was developed along with a monitoring system with the aim to increase reproducibility of these organs.

Methods: In 2018-19, a series of patients were accrued to use a new, in house BBPP. Patients were given specific instructions for bladder filling and bowel emptying. Radiation therapy staff checked compliance daily and recorded any deviations from the protocol in the patient technical notes. Daily cone beam CT (CBCT) was used to compare the volume of the OAR's to CT volumes. Volumes were scored using a locally developed scoring system and patients were given feedback based on the scores. OAR volumes using the new protocol were compared to a cohort of patients from 2013 that received CBCT on days 1, 2, 3 and weekly but did not follow a strict BBPP. These patients did receive full bladder instructions but no bowel prep. There was no daily feedback provided.

Results: CBCT images were reviewed and scored based on bladder and rectum size as compared to CT. Planning CT volumes of the OARs were also evaluated. The variability in bladder volume both at CT and on treatment was much reduced in the protocol cohort. We also found a decrease in large rectal distensions on treatment using the protocol. Rectal volumes were also observed to be significantly smaller at both CT and on treatment.

Conclusion: The use of a BBPP along with daily feedback significantly reduced the variability of bladder volumes and decreased the number of large rectal distensions during radiotherapy. The rectal volumes at both CT and treatment were also significantly smaller and less variable.

Planning comparison of field in field tangent breast radiation therapy using varian eclipse treatment planning system vs. Ezfluence, an automated planning software: planning time and quality

Helene Gaffney, Ankit Sondhi

Purpose: Breast tangent radiotherapy (RT) using field in field (FinF) technique accounts for up to 30% of fractions in many RT centres. The FinF planning approach using Varian Eclipse Treatment Planning System (TPS) is a manual and iterative process that can be highly time consuming and dependent on the skill of the treatment planner. A comparative study was performed to assess the implications of replacing manual FinF (mFinF) with an automated FinF (aFinF) approach using an automated planning software called EZFluence (EZF), version 2.3.1, (RADformation, New York, NY).

Methods: A cohort of 10 patients was selected with 5 receiving tangent RT to right breast and 5 to left breast. Each patient was planned using mFinF and aFinF. Time to complete the treatment plans (excluding time to contour by radiation oncologist and therapist) was recorded for each patient. All plans were also evaluated dosimetrically for breast tissue coverage, maximum point doses, lung volume avoidance and heart dose where applicable.

Results: Planning time was significantly improved using aFinF compared to mFinF (mean time 46 min for mFinF vs. 16 min for aFinF). Dosimetrically, aFinF plans generated using EZF were better or equivalent to plans generated using mFinF, with both approaches producing clinically acceptable distributions. Mean breast V95% 93.2±0.8 for mFinF vs. 95.6±0.6 for aFinF, with V105% reduced for aFinF. Mean maximum dose 105.9±0.3 for mFinF vs. 105.8±0.3 for aFinF was not statistically significant. Differences in lung and heart avoidance were also not significant.

Conclusion: An automated FinF approach using EZFluence significantly reduces plan development time. In addition, it generates dosimetrically superior (or equivalent) plans compared to manual FinF. For these reasons, automated tangent breast planning should be adopted to save time, resources and generate superior plans.

FDG Dose Reduction Based on NEMA PET Phantom Study

Alexander Hart

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Purpose: Fluorodeoxyglucose 18F (FDG) PET imaging is a powerful tool in the diagnosis of cancer and subsequent treatment planning. The recently in- stalled state-of-the-art PET/CT scanner at BC Cancer Vancouver Island Center has the ability to produce scans of superior diagnostic quality. Increased detector sensitivity, time-of-flight, and advanced reconstruction parameters mean that it should be possible to administer less activity. However, the scanner is not the only limiting factor. The scan duration, and patients themselves also influence image quality. Increasing patient dose may be necessary for larger patients, but protocols must be consistent with ALARA. The European Association of Nuclear Medicine currently recommends that PET centers determine the minimum activity for a 75 kg patient and then scale dose based on patient weight.

Methods: A NEMA PET phantom study was conducted with the background compartment filled with a uniform concentration of 2 kBq/mL and sphere concentrations of 20 kBq/mL. Scans were acquired in list mode to al- low for multiple reconstruction types and scan durations. Image quality was assessed by measuring recovery coefficients of the spheres and the coefficient of variation (COV) in the uniform background.

Results: The minimum scan duration was obtained using a threshold COV value of 15%. Based on the minimum scan duration and the assumption that activity and scan duration have an equal impact on image quality, the minimum activity was determined. For TOF OSEM reconstructed PET this resulted in an activity of 168 MBq, a reduction of 30% compared to the current clinical protocol.

Conclusion: The minimum FDG activity to achieve acceptable image quality was determined based on a phantom study. This activity is valid for a 75 kg patient only and an appropriate dose scaling regimen must be determined.

Conformal Ocular Brachytherapy in Alberta

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Purpose: The Alberta Ocular Brachytherapy program was established in October 2011 to treat tumors of the eye (primarily uveal melanomas) with episcleral plaques. This presentation provides a program overview, with a focus on major medical physics components.

Methods: Gold alloy eye plaques are loaded with I-125 seeds, and are sutured directly to the external sclera of the eye at a position corresponding to the location of the tumour inside the eye. The plaque is left in place for a duration of 4-7 days, during which it delivers a dose of 70 Gy, covering the entire GTV, plus a PTV margin around the base and tumour apex. Dose is minimized to critical structures in the eye, including optic nerve and macula. Dose calculation is TG-43 based, with corrections made for plaque heterogeneities, but assumes tissues are water-equivalent.
Methods for reducing critical structure dose includes conformal planning, asymmetric plaque loading and placement, and use of non-uniform seed activities.
Insertions are performed in Edmonton, and removals take place in either Edmonton (since 2011) or Calgary (as of 2018).

Results: Since the inception of the program, 400 patients from AB, BC, SK, MB, and the NWT have been treated. Local control of uveal melanomas (n= 386) remains 100%. Radiation induced papillopathy is observed at rates which increase as a function of dose to the optic nerve.
To date, 28 implants have been removed in Calgary following insertion in Edmonton. Patient have responded positively to the option of plaque removal closer to home.
Automatic optimization of the treatment planning process is a current research initiative.

Conclusion: The Alberta Ocular Brachytherapy program treats patients from a catchment area spanning most of western Canada. Ocular brachytherapy remains an effective technique for the treatment of intraocular tumours.

Squint – Efficient DVH-based plan comparison and evaluation using ESAPI

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BC Cancer – Center for the North

Purpose: Squint is a standalone ESAPI (Eclipse Scripting API) application for plan evaluation and comparison which addresses some of the limitations and inefficiencies of Varian's clinical protocol system. Squint is open-source and free to use and modify.

Methods: New protocols can be created using XML, converted from existing Eclipse protocols, or created from scratch within the application. Protocols are stored in a central database, and available to all instances of Squint running in the department. Plan data is acquired directly from Eclipse using the API. Once a protocol and patient are loaded, the user attaches the relevant plan(s) for assessment and the script applies some aliasing logic to match patient structures with constraints defined in the protocol.

The graphical interface allows side-by-side comparison of DVH endpoints between the competing plans, and evaluation of multi-phase protocols comprising multiple plans and plan sums. Adjustments made to the plan in Eclipse can be synchronized and re-evaluated by Squint on demand. Protocol variations can accommodate patient-specific needs in prescription and fractionation, with conservation of biological equivalent dose (BED) if desired.

Squint also provides a plan check window for a variety of parameters such as calculation details, CT simulation details, optimization objectives, prescription details, beam geometries, and stray pixel contours. Planned values are compared to reference values defined in the protocols, and Squint will flag any parameter that does not match, requiring further possible investigation into that parameter.

Results: Squint has been deployed within our dosimetry and physics departments, where it is used as part of the clinical workflow for plan comparisons and evaluation.

Conclusions: Squint streamlines the DVH-based analysis of plan quality and associated protocol management tasks, allowing physicists and dosimetrists to focus on other important aspects of quality improvement and control. Future work includes integrating additional plan assessment features such as expansions of PTV margin checks.

No more "spherical" patients: Path to improved radiosurgery treatment based on optimized beam angles

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Purpose: Linac-based Stereotactic Radiosurgery (SRS) treatment planning is an intensive process for multi-metastatic cases. Specific treatment plan parameters must be defined for each beam: the table angle, collimator angle, and gantry trajectory. Template-based planning provides an easy approach to standardize SRS planning, however, plans are not specific to the patient anatomy and target geometry. We expanded on a previously validated collision prediction algorithm, to maximize usable treatment space, by implementing a Beam Angle Optimization (BAO) algorithm, which automatically determines treatment plan parameters based on patient-specific geometry.

Methods: Five SRS patient plans, previously treated on the Truebeam Edge platform, were chosen for BAO. The number of metastases per plan ranged from 2-7, all treated with a single isocenter. The number of beams was kept constant between the clinical treatment plan and BAO simulated plan. Table, collimator, and gantry angles were automatically determined by the BAO algorithm, simplifying the complex beam placement process. Subsequently, BAO plans were re-optimized using the Eclipse v13.6 photon optimizer with the same dose constraints and normalized to meet the target dose coverage of the clinical plan. Dosimetric parameters for Organs-at-Risk (OARs) were compared between clinical treatment plans and BAO plans.

Results: The BAO cohort showed improvement for 16 of the 17 OAR parameters analyzed. Median max dose was reduced for the left optic nerve, optic lenses, eyes, chiasm, and brainstem. Normal brain tissue volume in the lower dose region (<10 Gy) was also decreased. Differences in OAR parameters were not statistically significant due to the small sample size (5 patients).

Conclusions: The automated BAO algorithm led to a reduction in dose to OARs compared to previously treated clinical plans. This feasibility study will be expanded to include plan isocenter(s) optimization, followed by a larger retrospective patient study to determine clinical impact.

Evidence-based PTV margin reduction for modern lung SABR using deformable registration

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Purpose: Standard planning target volume (PTV) margins for lung stereotactic ablative radiotherapy (SABR) at BC Cancer are 5 mm. High dose rate volumetric modulated arc therapy (VMAT) delivery using flattening filter free (FFF) beams with modern immobilization systems may allow for PTV margin reduction to 3 mm. This study analyzes internal gross tumor volume (IGTV) coverage for lung SABR cases planned with 5 mm and 3 mm PTV margins.

Methods: Lung SABR patients treated with 4 fractions, 10XFFF energy, and 5 mm PTV margins at BC Cancer – Prince George from 2016-2019 were included (N=35). Deformable registration of the original planning CT (average intensity projection from 4DCT) and IGTV contour to the post-treatment CBCT was completed for each fraction to simulate the worst case intra-fraction translation and rotation of the IGTV, and capture any volume changes. Due to inaccuracies intrinsic to deformable registration, each deformed IGTV (d-IGTV) contour was reviewed, using the CBCT as reference. Original plans were retrospectively re-planned with 3 mm PTV margins and re-calculated on each deformed CT to assess d-IGTV coverage (V100%). SPSS 14.0 was used for a paired Wilcoxon signed-rank test.

Results: The d-IGTV coverage for 22 of 35 cases has been analyzed thus far. The average d-IGTV coverage with 5 mm PTV margins was 100% with a minimum patient average (over 4 fractions) of 99.9%. The average d-IGTV coverage with 3 mm PTV margins was 99.9% with a minimum patient average of 98.4%. Notably, for 3 mm PTV margin plans only 3 of 88 fractions had d-IGTV V100% < 99% (98.9%, 97.9%, and 93.8%). Wilcoxon signed-rank test revealed no difference in average d-IGTV coverage between 5 mm and 3 mm PTV margins (p=0.066).

Conclusion: With modern treatment and immobilization techniques, reducing lung SABR PTV margins to 3 mm does not significantly reduce on-treatment IGTV coverage.

eFLASH Radiotherapy at BC Cancer – Vancouver

Claudia Mendez, Tania Karan, Peter Petric, Alanah Bergman, Don Ta, John Paul Sweeney, Alastair Kyle, Jennifer Baker, Taixiang Wang, Nan Nan Liu, Xinhe Liu, Judit Banath, Andrew Minchinton, Cheryl Duzenli

Purpose: We present a feasibility study of non-destructively modifying a standard clinical linear accelerator to deliver electron FLASH (eFLASH) dose rates (>50 Gy/second) and the dosimetry performed in preparation for radiobiological experiments.

Methods: To achieve eFLASH dose rates, a standard linac was run in 10 MV photon mode with an electron foil in the beam path instead of the target. An Arduino-controlled circuit was used to control the linac gating interface to produce millisecond beam-on times. Experimental samples were placed at the level of the X jaws resulting in dose rates up to 300 Gy/s at the point of measurement.
Dosimetry for eFLASH and standard clinical setup was evaluated with a 0.01 cc volume Wellhöfer ion chamber and validated with optically-stimulated luminescence dosimeters (OSLD) and Gafchromic EBT3 film. Percent depth dose (PDD) curve and profiles were obtained using film. A reference ion chamber was used to determine doses delivered at the central axis for all irradiations.
Doses of 5, 10, 15, 20 and 25 Gy were delivered for all experiments, with eFLASH irradiation times ranging from 20 to 100 ms.

Results: The eFLASH PDD curve showed beam characteristics comparable to a clinical, standard set-up 9 MeV beam. The eFLASH field size was ~20x20 cm as measured at full-width at half maximum on film profiles, with a central ~10x10 cm area that received 90% of the intended dose. Passive dosimetry showed good agreement with ion chamber doses, however our current method of OSLD readout limited the dose accuracy past 20 Gy. Machine quality control was performed after the completion of the experiments to confirm machine was still clinically operational.

Conclusion: An eFLASH experiment was successfully performed on a clinical linear accelerator. Sources leading to dose rate instability warrant additional investigation.

Comparing different methods of assessing the safety of complex treatment plans with dynamic tumour tracking on the Vero4DRT linear accelerator

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Purpose: The Vero is capable of real-time dynamic tumour tracking (DTT). However, DTT plans are optimized and calculated only on a single respiratory phase (eg. exhale) despite the beam's panning/tilting motion. In this study, we compare two methods that re-calculate a plan on a different breathing phase to assess if a plan is safe for treatment.

Methods: Step-and-shoot intensity modulated radiation therapy (sIMRT) plans were created for 11 patients. The plan was optimized on the exhale phase CT then re-calculated on the inhale phase CT using two different methods: 1) the beam motion during tracking was simplified to a translation, and 2) the gimbal rotation of the beam was correctly modelled using a script developed in-house. For both methods, the inhale dose was then deformed to the exhale CT and accumulated with the original dose. The maximum dose for certain organs at risk (OARs) was compared between the two methods.

Results: In total, 37 OARs were examined. Both the first and second methods found 4 OARs exceeded their dose limits on the inhale phase that did not exceed their limits on the exhale phase. Dose deformation of the inhale dose to the exhale CT and accumulation with the original dose shows 2 OARs exceed their dose limit via the first method and 3 via the second method.

Conclusions: DTT plans optimized for a single breathing phase leave an OAR vulnerable to exceeding its dose constraint during other breathing phases. Modelling DTT beam motion as a translation is simpler to implement, but produces different results than when the beam pans/tilts. Dose accumulation to a reference phase should be used during planning to ensure an optimal dose distribution is achieved.

The Vancouver Island experience in prone breast radiotherapy - moving forward

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BC Cancer – Victoria

Purpose: Prone breast irradiation was proven to reduce heart and lung doses in breast cancer patients receiving adjuvant therapy. Recently, a Canadian randomized trial showed that treating large breasted women with IMRT in the prone position significantly reduced the occurrence of acute skin toxicity when compared to supine position. BC Cancer-Victoria participated in the trial and due to its favorable outcome prone treatment is now available for all eligible large breasted women. In order to implement the prone breast technique in a busy clinical setting we needed to develop a simple workflow, increase planning efficiency and reduce treatment time slots.

Methods: Prone breast setup is challenging for patients as well as RTs. New prone breast boards were acquired for patient comfort and reproducibility. All procedures were reviewed and amended. 10 randomly selected patients previously treated with Hybrid_IMRT in the prone position were replanned using an automatic treatment planning software EZFluence (EZF) (Radformation Inc, NY), script available in Eclipse. Plans were compared regarding dosimetry, planning time and total MUs. Hybrid _IMRT uses 2 tangential open fields and 2 IMRT inversely optimized fields with the same geometry. In order to create an automated skin flash for the IMRT fields, extra contours are needed. With EZF the optimal fluence and skin flash for IMRT fields are generated automatically and then imported into Eclipse for dose calculation. Al plans were evaluated with Vancouver-Island Monte Carlo system.

Results: Compared with Hybrid_IMRT which usually took 2-3 hours to develop, the EZF plans were generated between 3-4 minutes with the same plan quality. Using EZF, the total MUs was reduced on average by 10%. Employing CBCT to set-up the patients the treatment time slots are 30 minutes.

Conclusions: Prone breast treatment is now seamlessly integrated in a busy department.

A programmatic approach to automation in radiotherapy at the TBCC

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Purpose: To incorporate automation tools and theory in a multi-faceted approach to improve the standard of care for radiotherapy patients.

Methods: Automation implementation was utilized across clinical, research, and education programs. Clinically, automation tools have been developed following AAPM TG 275 recommendations and implemented to evaluate plan quality, deliverability, and protocol adherence. Research automation tools and a data request process have been implemented to facilitate multidisciplinary research and quality improvement investigations. To strengthen, broaden, and ensure a robust automation program, a local curriculum was developed to provide the necessary background information on software design patterns required to write readable, re-usable, extendable, and testable software that utilizes the Eclipse Scripting API for use within a clinical environment.

Results: Since 2018, over 4100 patient courses by 16 physicists have been evaluated using automated tools for plan quality and deliverability. Tumour site-specific protocols are utilized to evaluate compliance and the pilot site group (prostate) has been implemented on over 70 patients. Complex DVH automation tools have been utilized by 16 researchers and resulted in both manuscripts and abstracts that would have otherwise been prohibitive. Lastly, the local curriculum was delivered to eight learners over the course of 10 weeks to ensure capability of future developments and robust automation tool development.

Conclusion: We have developed the foundation of an automation program based in standardization, efficiency, and scalability to improve radiotherapy capabilities in clinical, research, and education.

Parameter optimization for multi-contrast imaging using photon-counting CT

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Purpose: Photon-counting computed tomography (PCCT) shows promise for medical imaging in regards to material separation and imaging of multiple contrast agents for both preclinical research and in the clinic. However, many PCCT setups are currently under development and may not be optimized for specific contrast agents or use cases. Here, we demonstrate how system parameters may be varied experimentally in order to optimize system performance.

Methods: A table-top PCCT system was used to image four high atomic number contrast agents (gadolinium, dysprosium, lutetium, and gold) in a small phantom. The contrast agents were then separated and the concentration was quantified using K-edge imaging. In order to optimize the system, we investigated three parameters experimentally: filter type and thickness, projection acquisition time, and energy bin width around the K-edge of a contrast agent. The results from the various parameters were compared based on CT signal and CNR or noise in K-edge images. The concentrations of the contrast agents were also quantified using K-edge images and compared to known concentrations to determine the accuracy of the reconstructed concentration.

Results: Our bench-top PCCT system was able to separate multiple contrast agents of similar atomic number through K-edge subtraction. Projection acquisition time optimization showed an expected decrease in K-edge CNR and an increase in K-edge noise as projection time decreased. However, filter type and bin width demonstrated a dependence on the specific contrast agent. In addition, our system was able to successfully determine contrast concentration in normalized K-edge images.

Conclusions: The presented bench-top system demonstrated the ability to separate multiple contrast agents using K-edge subtraction and to accurately determine contrast concentration in K-edge images. For parameter optimization, the choice of specific parameters for future preclinical or clinical use will need to be chosen based on contrast agent and other considerations such as image noise.

Novel User-friendly Software to Streamline QA of HDR Brachytherapy Plan

Manuel Rodriguez

Purpose: To design and create a HDR Brachytherapy plan QA platform that effectively and efficiently streamline the process and effortless check dosimetry and potential errors without missing steps. It also automatically records the results in a logbook and attaches the independent 3D dose verification to the patient plan in BrachyVision.

Methods: A window-based software (BrachyVIC) has been designed in-house and coded in Python to perform and track the tasks required in HDR Brachy plans QA. The dosimetry 2nd check is calculated using AAPM TG43 formalism. The dose calculation module generates a tree-dimensional dose matrix of 5mm voxels based on plan dicom files exported from BrachyVision. DVHs are calculated based on the dose delivered to small volumes of 0.25x0.25mm2 times the thickness of the CT slice (1.25mm/2.5mm). The independently calculated 3D dose matrix is converted to dicom file and exported back to BrachyVision for additional comparison and/or for documentation purposes. The software also exports the data to the Excel Radiobiology Sheet for EQD2 OAR assessment with other EBRT treatments. Additional checkboxes are included to review prescription, applicator digitalization, applicator dimensions, reference point. BrachyVIC will not store QA documentation unless tasks are checked.

Results: The DVH difference between BrachyVision and BrachyVIC are within 2%. The dose and structure volume data of the OARs are accurately, fast, and effortless transferred to radiobiology sheets for RO's assessment and to logbook for documentation. No QA step in the process is overlooked or missed as 2nd check physicist is obliged to mark the checkboxes in order to be able to document the results/review in the logbook.

Conclusion: The HDR Brachy plan QA is now more effective and efficient, and less prone to mistakes. No manual input is needed (typing data) and no step is overlooked which results in less patient waiting time and higher confidence in treatment delivery.

Timeline of Symptoms Leading to the Discovery of Damage to a Varian Clinac Target

Conor Shaw, Charlie Kirkby

Jack Ady Cancer Centre

Purpose: To describe the series of events leading to the discovery of a pit in the target of a Varian Clinac iX linear accelerator (linac) at the Jack Ady Cancer Centre (JACC), and its effect on the beam characteristics.

Methods: Data was gathered through a review of quality assurance (QA) records in the months leading up to the target change.

Results: In early December 2019, some gradual changes began to manifest in the parameters measured by the Daily QA3 device (Sun Nuclear) for one of the Clinac 21iX units at the JACC. Throughout the month, there were gradual changes in radial symmetry and output until a sudden change of both took the unit out of service. Physicists at Tom Baker Cancer Centre (TBCC) noted similar deviations in radial symmetry and output on a Varian Trilogy Linac prior to a target replacement in 2014 [1]. At JACC, the earliest indicator of the issue appeared to be the energy parameter measured by the DailyQA3 device, which is a symmetry-adjusted flatness [2]. It showed a steepening increase throughout December. Also, the 'Yield' (comparing target current and dose rate) measured by Varian's *Clinac Support System Application* (CSSA) showed deviations beginning in early December.

Conclusion: Changing a target is a major clinical and service task, so the earlier plans can be made for replacement, the better. Fluctuations in output and symmetry are common indications of a target issue, with symptoms appearing a couple of months prior to the time that the severity requires removing a unit from service. In our case, the most sensitive indicators were the 'Energy' parameter measured by the DailyQA3 device and the 'Yield' measured by the CSSA. Our group is currently modelling pitted targets in Monte Carlo to attempt to determine beam characteristics that may be able to provide earlier confirmation of target damage.

References

[1] Hudson A., Weibe J., Ploquin N. and Pierce G. Unexpected output Drops: Pitted Blackholes in Tungsten. Canadian Organization of Medical Physics 60th Annual Scientific Meeting, Banff, AB, July 9-12th, 2014

[2] Daily QA 3™ Reference Guide: Daily QA Accelerated, Sun Nuclear Corporation, Melbourne Florida, 2009

ALIGN RT – Surface guided radiation therapy as used at VIC

Valerie Small, Kristy Abrahams, Sergei Zavgorodni

Purpose: Align RT provides live monitoring of patient movement during radiation therapy. In case of movement during treatment, the beam is automatically triggered to hold until correct positioning is re-established.

Methods: A set of three camera pods mounted on the ceiling project a speckle pattern of light onto the patient's surface. This is reflected back to sensors which reconstruct the patient's 3D surface. By focusing on a therapist-defined region of interest, (which considers the open face part of the shell, and excludes the rigid shell surface), the patient's position relative to the reference image can be tracked, in 6 degrees of freedom – vertical, longitudinal, lateral, rotation, pitch and roll. Being connected to the TrueBeam treatment unit, the tracking system can suspend treatment should it detect the patient has moved. We can treat small volumes to high doses, with continuous feedback of the patient's position, secure in the knowledge that should the patient drift outside of set tolerances, the beam will automatically hold until the patient is brought back within the tight parameters.

Results: Approximately 250 stereotactic brain patients have been treated at VIC with the benefit of Align RT. The Align system aids in patient set-up before even leaving the treatment room. It reliably provides real-time feedback of patient motion during treatment, and holds radiation when the patient is outside of set tolerances. Post treatment cone beam CTs have confirmed that the patient maintained the correct position, corresponding with Align values.

Conclusions: Align RT has served as a reliable motion management device over 3 years and more than 250 patients. Post RT cone beam CT scans showed correlation with Align tracking data. The system is well tolerated by patients, and gives peace of mind to the treatment team for accurate treatment delivery.

3D Printing Silicone Bolus

Nathan Smela, Piotr Dubrowski, Andrea Wolowski, Nick Chng, Quinn Mathews, Kim Lawyer, Sunny Chang

Purpose: To reliably create cost-effective silicone boluses tailored for each patient.

Methods: We export a 3D Bolus from Eclipse using an in-house program. We then design and 3D print a single mold, shaped to the bolus exported. That mold is printed in either PLA or PVA plastic, which is filled with a two-part silicone mixture and left to cure. Once cured, the mold is scanned in a CT scanner, evaluated for air holes and uniformity, and registered to the original bolus contour in Eclipse. If acceptable, we destroy the mold to free the silicone bolus.

Results: Boluses created are highly accurate and conform well even after patient weight loss. Typical costs are nearly equivalent to using Superflab. Time to create a bolus can take a day or two, but require little "hands-on" time. Ease of destroying the mold depends on the material used, which affects overall cost.

Conclusion: Custom-shaped silicone boluses are feasible. If cost is not an option, PVA filament is ideal to easily remove the silicone from the bolus. If attempting to save costs, PLA is a substitute, but will require additional time and tools to safely remove the bolus from the mold.

Development of a Phantom Incorporating Simultaneous Cardiac and Respiratory Motions

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Purpose: Stereotactic arrhythmia radioablation (STAR) is susceptible to inaccuracies due to respiratory and cardiac motions of the target. Commercial phantoms capable of respiratory motion allow for dosimetric validation of respiratory tracking radiotherapy; however they do not address the issue of coupled cardiac motion. Prior work showed the feasibility of cardiac-lead based markerless tracking on the VERO4DRT linear accelerator. In this work a cardiac motion device was developed and used in conjunction with the QUASAR respiratory motion phantom to produce simultaneous cardiac and respiratory motions.

Methods: A phantom consisting of a linear actuator motor driving a 3D printed arm was developed. The motor was controlled by an Arduino Uno microcontroller and motor driver shield allowing for variations in the displacement and frequency of the arm holding an Implantable Cardiac Defibrillator (ICD) lead. The microcontroller and motor were enclosed in the housing assembly that attaches to a custom insert for use in the QUASAR respiratory motion phantom. The assembly allows the ICD lead to move in the anteroposterior (AP) or mediolateral (ML) axis depending on assembly orientation, while the entire insert moves in the cranio-caudal direction.

Results: The device was evaluated and is capable of generating motions in the range of 2 and 35mm and a frequency between 0.5 to 2.5Hz which corresponds to heart rates of 30 to 150 beats per minute. The device can be incorporated into the Quasar respiratory phantom and produce simultaneous cardiac and respiratory motion.

Conclusion: The phantom replicates typical cardiac-type motions spatially in either the AP or ML direction with programmable pulse rates to adjust heart rhythm. The cardiac motion device has been incorporated with the Quasar phantom with the intent to further test the feasibility to markerless tracking of ICD leads moving with respiratory and cardiac motion.

Susceptibility Induced MRI Geometric Distortion Prediction

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Purpose: The SPIne response assessment in Neuro Oncology (SPINO) guidelines have recommended fusion of thin sliced MRI sequences with treatment planning CTs during SABR treatment planning to aid tumour delineation within the bone marrow of spinal segments. For cases where the patient has pedicle screws implanted for spine stabilization, spinal cord localization and MRI geometrical fidelity becomes compromised due to susceptibility effects. This work investigates how magnetic field perturbation modeling could be used to predict the geometric distortion around a pedicle screw.

Methods: A KV image of a Medtronic (Dublin Ireland) pedicle screw was acquired on a TrueBeam linear accelerator (Varian Medical Systems, Stanford, California). From the image a radial profile and subsequent cylindrically-symmetric 3D susceptibility value map of the pedicle screw in water were created. Susceptibility values ($\Delta\chi$) of 181, 772 and -9 ppm representing Titanium, Cobalt Chromium and Water respectively were used for the map. The magnetic field distribution originating from the metal pedicle screw (B_o') for a 1.5T B_o field was calculated from the susceptibility map using Fourier based methods. The 3D geometric distortion map was then generated by dividing B_o' by the read gradient field strength (7 mT/m) in the example case. For our simulation the long axis of the pedicle screw was oriented in the AP direction, B_o was oriented in the sup/inf direction and the read gradient was oriented in the Left/Right direction.

Results: For this particular simulation MR distortions between 0.3 and 4 mm were seen in the regions that would pertain to areas in and around the spinal cord.

Conclusion: Magnetic field modeling may provide a way to correct susceptibility induced geometric distorted MR images. Experimental work is required to validate the accuracy of the model used in this work.

Titanium Susceptibility Measurements of Spine Hardware

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Purpose: Precision radiation therapy such as spine SABR requires geometrically precise MR imaging. In order for the influence of spinal transpedicular screws and posterior stabilizing bars on the spatial linearity of MRI scans to be properly modeled, the magnetic susceptibility of the orthopedic hardware must be accurately known. Tabulated values are available, but are greatly dependent on the exact alloy used in manufacture. As such, a direct experimental determination may be necessary. In this work, we evaluated a titanium sample material with precisely-known dimensions in an MRI scanner to determine its magnetic susceptibility experimentally.

Methods: A titanium rod was obtained from Medtronic (Dublin Ireland). The rod was a cylindrical structure (5.5 mm diameter, 80 mm length). The cylinder was vertically fixed to the bottom of a 1 L glass and surrounded by water. This was then imaged in a 3T Philips MRI scanner to determine the induced field map. A double-echo scan with a separation of 200 µT was used to measure the phase change between echoes, thereby allowing calculation of field. The scan was a single slice cutting through the centre of the cylinder. This experiment was repeated without the metal cylinders present, providing a baseline field map that could then be subtracted out. Subtraction generates a map that corresponds to the metal alone. A simulation in Matlab was developed to predict the field map from these structures; the simulated magnetic susceptibility was tuned until it matched experimental findings.

Results: This method determined the titanium alloy to have a magnetic susceptibility of 199.3 ± 0.15.

Conclusion: Experimentally-derived values differ from tabulated values (Ti), demonstrating the necessity of experimental verification. Measured susceptibility values may be used for geometric correction post processing in the future.