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SBRT for localized prostate cancer using single arc VMAT: plan quality, complexity, dose delivery accuracy, and efficiency

Prospective/Objective: Plan quality, complexity, dose delivery accuracy and efficiency were compared for low- and intermediate-risk prostate stereotactic body radiation therapy (SBRT) on a C-arm LINAC. Three different volumetric modulated arc therapy (VMAT) arrangements were investigated in order to minimize the treatment time, therefore reducing the intrafraction prostate motion uncertainties, while meeting the clinical objectives.

Materials and methods: A retrospective dataset of 11 patients was used. All plans were designed to deliver 40 Gy in 5 fractions to the prostate planning target volume (PTV) using a VersaHD C-arm linac (Elekta AB, Stockholm, Sweden). Two full arcs 6 MV flattening filter free (FFF) plans were compared to single full arcs using both 6 MV FFF and 10MV FFF. A plan quality index (PQI) was calculated to compare the achievement of treatment goals after optimization. Plan complexity was evaluated with the modulation factor. The dose delivery accuracy and efficiency were investigated with patient-specific quality assurance (PSQA) of all VMAT plans using the Octavius 4D phantom and the 1500 Detector (PTW, Freiburg, Germany).

Results All treatment plans met the planned dose constraints. No statistical differences were found in the PQIs and MUs comparison among the three techniques. The PSQA plans of all three techniques passed the γ criteria of 2%/2 mm with mean γ passing rates > 96.5%. As expected, the techniques using single arcs showed a statistically significant decrease in the delivery time. The mean delivery times were 1.6 min (corresponding to a reduction of -46%) and 1.3 min (with a reduction of -56.2%) for 6 MV FFF and 10 MV FFF respectively.

Conclusion: High-quality plans have been achieved with reasonable complexity using single arcs VMAT for prostate SBRT. The reduction in treatment time, the accuracy and the reproducibility of the dose delivery of single-arc FFF treatments demonstrated that the proposed strategy is feasible for low- and intermediate-risk patients. In particular, the lowest delivery time required for 10MV FFF clearly demonstrated the advantage of this strategy in reducing intrafraction prostate uncertainties.

Evaluation of feasibility of using RayStation treatment planning system as an independent dose calculation system for the Unity MR-linac

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Prospective/Objective: MR-guided radiotherapy (MRgRT) offers advantages over traditional x-ray methods, including enhanced soft-tissue contrast, real-time capabilities, and the ability to adapt treatment plans based on daily MR imaging. While measurement-based patient-specific QA methods are suitable for the Elekta Unity MR-linac, the impracticality of verifying adaptive plans with phantom measurements before treatment calls for a more efficient solution. However, for MR-linacs the dose calculation tends to become complicated with the existence of magnetic field. Therefore, only a few dose/MU check programs for Unity MR-linac were commercially available so far. The primary goal of this thesis is to examine the resemblance of dose distributions, generated by RayStation and Monaco, and to evaluate the feasibility of using RayStation TPS as a secondary dose calculation software for the purposes of MR Unity PSQA. Additionally, the second goal is to evaluate the feasibility of using RayStation as a basis for a measurement-less PSQA approach.

Materials and methods: Since RayStation does not simulate the influence of the magnetic field and has differences in dose calculation algorithms compared to the native Unity TPS (Monaco), two correction approaches were proposed and tested to enhance similarity between these TPS. Twenty clinical cases each for the brain and head & neck were exported to RayStation, and corrections were applied. Subsequently, the corrected dose distributions were compared to the original Monaco plans using gamma analysis, and the results were assessed against AAPM TG 219 recommendations. The correlation and agreement between RayStation and Monaco datasets were evaluated using Pearson Correlation Coefficient calculations and the Bland-Altman plot method. Finally, ten verification plans for both the brain and head & neck were recalculated in RayStation, and the results were compared with ArcCheck measurements to assess theoretical dose distribution similarity with real machine performance.

Results: An optimal 0.13 isocenter shift, both perpendicular to the magnetic field and along the central beam axis, was established to simulate the magnetic field's influence. Four different MU correction methods were proposed to address differences in dose calculation algorithms. The gamma comparison of all 40 plans (RayStation vs Monaco) revealed a passing rate exceeding 90% of points with gamma values ≤1 (3%/2 mm, 10% dose threshold). However, only a limited number of RayStation plans achieved a 90% passing rate in gamma comparison with ArcCheck measurements (RayStation vs ArcCheck). Only negligible correlation was observed between RayStation-related datasets and measurement results. Despite this, RayStation-related datasets demonstrated agreement with the measurements.

Conclusion: While the Bland-Altman plot method demonstrated agreement between RayStation-related datasets and measurements, the lack of correlation with ArcCheck measurements prevents the use of PSQA values of RayStation plans to predict specific measurement results. Despite the established agreement by the Bland-Altman plot method, the relatively high deviation in gamma analysis results (RayStation vs Monaco) widens the predicted range of differences (95% confidence limit), making it impractical for use. Nevertheless, the theoretical dose distributions' similarity between the two TPSs, meeting AAPM TG 219 criteria, supports the introduction of RayStation as an independent dose calculation system for the Unity MR-linac.

End to end verification in gated-treatment delivery: a comparison between motion phantom devices

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Prospective/Objective: to evaluate the impact of gated treatment and non-gated treatment from imaging to delivery and to quantify the impact of gating amplitude on the treatment delivery by means of phantom simulation and measurements.

Materials and methods: To achieve our goals, a CIRS Model 008A Dynamic Thorax Phantom and quasar programmable respiratory motion management phantom (QPRMP) was used. Standard and custom inserts with films were employed to mimic lung motion for end-to-end test measurements within the phantom. Using a Toshiba 16-slice CT scanner, we simulated phantoms and acquired 4DCT datasets by binning respiratory cycles triggered by the Varian RPM system into ten phases. Two plans were created in the Varian Eclipse Treatment Planning System for delivery: one delivered using the gated system (gated plan) and one without it (non-gated plan). The gated treatment plan delineates the target within a single breathing cycle phase, whereas the non-gated plan represents an average of ten static phases for targeting. The treatment plans were compared to evaluate the benefits of gated versus non-gated approaches in managing tumor motion. Radiochromic films EBT3 irradiated inside the moving phantom were used to assess the accuracy and the reproducibility of the treatment.

Results: In both for gating at 10% of the amplitude and 50%, we have a significant dose reduction compared to the non-gated as expected. The gated treatment by reducing the volume of the target spares high-dose spillage to non-target structures and enhancing dose distribution conformity compared to the non-gated. Film measurements showed optimal agreement between the calculated dose and measured dose distribution for gating at 10% of the amplitude with gamma passing ratio of 99, 4%. This value demonstrates the optimal quality for the end-to-end test. Yet, it decreased to 82.1% (failing the gamma test) when the gating amplitude was adjusted to 50%, highlighting the significant impact of gating amplitude on treatment efficacy.

Conclusion: Gated treatment outperforms non-gated approaches in managing tumor motion. However, finding the optimal amplitude is crucial. Smaller amplitudes improve treatment quality but prolong time. Striking a balance is key, ensuring an effective treatment while optimizing time efficiency.

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Commissioning And Quality Assurance Of A New PET/CT

Prospective/Objective: The PET/CT performance has a direct clinical impact. This study evaluated the physical performance of a new SiPM-integrated digital PET/CT scanner, uMI Vista from United Imaging Healthcare, installed in our Institute, comparing the Vendor tool results and free available software.

Materials and methods: Following the NEMA NU-2 2007 standards, and using the specifics phantoms, spatial resolution, sensitivity, scatter fraction, accuracy and image quality tests were evaluated on the PET system. Spatial resolution was assessed by imaging three radioactive point sources in the air. System sensitivity was measured by using a NEMA sensitivity phantom. As described in the standard, we used a solid polyethylene cylinder with a line source positioned parallel to the tomograph axis at a few radial distances to measure the scatter fraction, and image quality was assessed with PET NEMA IEC phantom filling the four smaller spheres with radioactive solution and the two big with non-radioactive water. We processed the NEMA images acquired during the various tests with ImageJ software and compared the results obtained with those given by the manufacturer's software. The image quality and radiation dose were examined as part of the CT acceptance test using CATphan 600, system phantom, and standard PMMA phantom. The tube voltage and the HVL of the X-ray tube were also evaluated using an Unfors multimeter. The CT data have been analysed with IQworks software and Microsoft Excel.

Results: With the Vendor tool, the radial/tangential/axial FWHM were 2.99/2.99/3.03 mm and 5.54/5.24/5.26 mm at 1 and 10 cm off-centre, respectively, while using ImageJ they were 2.96 $\pm$ 0.04/ 3.10 $\pm$ 0.05/ 3.15 $\pm$ 0.05mm and 3.47 $\pm$ 0.025/ 3.22 $\pm$ 0.03/ 3.32 $\pm$ 0.02mm. Sensitivity at centre and 10 cm FOV given by the Vendor tool were 8.998 and 9.001cps/kBq, respectively, while they were very different using ImageJ. The results given by the Vendor tool showed that at a clinically relevant activity concentration of 19.78 kBq/cc of 18F-FDG, a Peak NECR is 122.58 kcps and scatter fraction 38.79%, while the percent error below the peak NECR was 3.03 %. The contrast recovery of 10, 13, 17, 22, 28 and 37 mm sphere diameters given by Vendor tool were 59%, 81.4%, 86.8%, 94.7%, 82.1% and 85.5%, respectively, while the background variability were 4.5%, 3.7%, 2.8%, 2.1%, 1.6% and 1.3%, respectively. ImageJ analysis gave 48%, 66%, 73%, 85%, 84% and 90% for the contrast recovery, and 3.8%, 3.1%, 2.6%, 2.3%, 1.9% and 1.5% for background variability, respectively. The lung error residual mean was 2.8% and 2.9% using the Vendor tool and ImageJ. Finally, the CT image quality and CTDI values resulted in the hospital's acceptance range.

Conclusion:

All the performance tests carried out on our new PET/CT were in the acceptable range given by the manufacturer, and the results of CT scanner were also acceptable for clinical use. This new scanner meets the highest standards of precision and safety and it opens new possibilities for patient diagnostic and treatment in our hospital.

Analysis and validation of the TQA quality assurance system in tomotherapy

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Prospective/Objective: Tomotherapy combines the precision of intensity-modulated radiation therapy (IMRT) with the geometric layout of a computed tomography (CT) scanner, proving highly effective for treating various oncological diseases. The success of Tomotherapy relies on precise treatment delivery, ensured by the Tomotherapy Quality Assurance (TQA) system. TQA is a comprehensive software that performs pre, during, and post-treatment checks, including equipment, output and energy control, and dosimetric checks. Though complex and requiring specialized knowledge, TQA's clear benefits lie in ensuring high-quality care while optimizing time and personnel resources.

Materials and methods: The checks provided for in this program can be carried out with the equipment supplied by the company together with the Tomotherapy equipment integrated with a few other instruments normally and easily available in a radiotherapy centre. In particular, the necessary equipment consists of: TomoPhantom cylindrical phantom supplied, Rectangular solid water phantom composed of several overlapping layers of different thicknesses supplied with the tomotherapy system, ater phantom equipped with a mobile arm with automatic movement system supplied with the tomotherapy system, Pencil chamber type ionization chamber at least 17 cm long with constant response along the entire length, Software for the acquisition and analysis of transverse, longitudinal and in-depth dose profiles acquired with ionization chambers in solid water phantom or water phantom, Cylindrical ionization chambers of the “minichamber” type (collection volume 0.056 cm^3 .

Results: Measurements made with ionization chamber in a solid water phantom (Cheese- Phantom and Slab-Phantom) have become the baseline values for the reference dose of a standard IMRT plan and for an energy control parameter (PDD20-10). Before starting the treatments, patient-specific checks are routinely carried out on a cylindrical diode array (ArcCheck – Sun Nuclear) and the results obtained on the patients demonstrates excellent agreement after the gamma analysis (3% - 3 mm). Simultaneously with the creation of a baseline for reference dose and PDD (Percentage Depth Dose), the baselines were acquired via direct measurement with the integrated array of detectors into the TQA (Tomo Quality Assurance) software. This method of measurement and processing dosimetric data has made possible obtain an estimation of numerous fundamental parameters of the system.

Conclusion: TQA platform has demonstrated to be reliable in monitoring the main parameters of Tomotherapy. The main advantage is the low time needed to acquire and analyze data. against a Farmer chamber. The Acuros calculation algorithm in Eclipse greatly underestimates the out of field dose and can be used only for a rough estimation in points not so far from the central axis of the beam (less than 20 cm). Ultimately, the Tomotherapy system analyzed was consistent with the specifications provided by the manufacturer and international protocols and has remained so over time.

Dosimetric Evaluation of Prostate Motion using Multimodal Imaging on Extreme Hypo-fractionated SBRT

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Prospective/Objective: Evaluate the dosimetric effect of prostate intrafraction motion on extreme hypo-fractionated SBRT treatments performed in Modena University Hospital, where SBRT-VMAT 6 MV FFF treatments for PCs are delivered using an Elekta VERSA HD accelerator with on-board CBCT X-ray Volumetric Imager (XVI®, Elekta Oncology Systems), and the image guidance of a Clarity Autoscan Ultrasound Based System (Elekta, Stockholm, Sweden) with transperineal probe for prostate movement monitoring and management.

Materials and methods: The data used for the analysis corresponded to 10 prostate acinar adenocarcinoma cases. The prescription was 36.25 Gy total dose in 5 fractions delivered every other day. The information relative to the mean movement of the prostate during each delivered fraction of the treatment for each patient was retrieved through the Clarity Autoscan Ultrasound Based System, to calculate an approximation of the motion-inclusive dose distributions and evaluate the dose difference between the planned and motion-inclusive dose considering the fulfillment and variation of the dose values related to the clinical constraints. Moreover, a tendency of the prostate movement was found and correlated to the dosimetric impact of under coverage of target and overdosage of OARs.

Results: Prostate movement in posterior direction seems to be recurrent during delivery of the treatment. For the target, dose under coverage as large as 4% (124 cGy) respect to the constraint value (D98% > 95%) has been observed in some individual motion-inclusive simulated fractions (16% of the total number). Only rectum and penis bulb showed a worsening in achieving the clinical constraints due to the prostate movement, yet only for a few fractions.

Conclusion: The mean shifts of the prostate during delivery of the radiation treatment don't generate a significant worsening in achievement of the dose constraints in the surrounding organs at risk. For target coverage, a violation of the D98% dose value constraint was found in a little number of fractions, yet over the course of treatment this issue won't be relevant as the displacements large enough to generate an insufficient target coverage are infrequent.

Evaluation of a new secondary independent dose calculation tool in VMAT treatment planning.

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Prospective/Objective: IMRT and VMAT have become the predominant radiotherapy techniques for a variety of treatment sites. The steep dose gradients generated by means of dynamical multileaf collimator motion, gantry rotation speed and dose rate can increase potential errors. Consequently, extensive pre-treatment quality assurance program is needed for the dosimetric verification of the plan, in order to ensure the accuracy and safety of the treatment. The purpose of this work is to perform pre-clinical evaluation of the Delta4 Insight (Scandidos, SWE) as a quality assurance system capable of three-dimensional dose calculations on patients Computed Tomography dataset and a model-based Monte Carlo algorithm comparing it with a reference TPS "Monaco".

Materials and methods: 3 planning situations have been considered: 3D plans in a 30×30×30 cm3 cubic phantoms created by superimposing slabs of varying densities to test the dose calculations within homogeneous structures and inhomogeneities in order to compare PDDs and dose profiles in different depths for both Monaco and Delta4 Insight; VMAT plans in a phantom based on the Task Group 119 and finally, 18 real patient plans in different anatomical sites, to evaluate real clinical situations, using a VMAT technique too. Calculations have been performed for 6 MV and 6 MV FFF photon beams.

Results: For the homogeneous cubic phantom, the mean values of the PDDs confidence limit for 6MV and 6MV FFF forced were (0.50±0.08) and (2.40±0.22), for non-forced (1.19±0.29) and (1.66±0.26), and the mean values of the profiles were (0.84±0.53) and (0.88±0.46). The mean values without forcing the structure (0.79±0.42) 6 MV and (0.75±0.33) 6MV FFF. Cubic phantom with internal low-density the mean values for the PDDs 6MV and 6MV FFF with 5 cm Inhomogeneity were (1.45±0.55) and (1.19±0.19). And for 10 cm (1.75±0.39) and (1.95±0.38). Profiles mean values for 6MV and 6MV FFF with 5 cm of Inhomogeneity were (0.83±0.45) and (0.71±0.33). And with 10 cm (1.02±0.51) and (0.70±0.31). For the cubic phantom with 3 cm internal low- and high-density inhomogeneity the mean values of the x-axis confidence limit for 6 MV and 6 MV FFF were (0.81±0.59) and (0.82±0.47). Regarding to the TG 119 phantom plans, the mean values of the GPR for 6 MV with different criteria were (82.4±5.7) 1%-1mm, (97.4±2.0) 2%-2mm and (99.6±0.3) 3%-3mm. And for 6 MV FFF (85.8±4.4) 1%-1mm, (98.8±1.0) 2%-2mm and (99.9±0.1) 3%-3mm. Finally for the 18 Real patient plans the mean values of the GPR for H&N and different criteria were (79.9±7.3) 1%-1mm, (95.7±2.8) 2%-2mm and (98.5±1.1) 3%-3mm, for Thorax (75.9±10.6) 1%-1mm, (93.9±4.0) 2%-2mm and (97.9±1.6) 3%-3mm, finally, for Pelvis (72.1±3.3) 1%-1mm, (93.8±2.1) 2%-2mm and (97.9±1.0) 3%-3mm.

Conclusion: This study revealed differences in profiles and PDDs, indicating a deviation from the expected shape and calculated dose levels. The comparison made performing the gamma analysis showed no significant discrepancies in both TG 119 and real patient plans, but the DVH comparison showed that DI always delivers higher doses to target and organs at risk, due to the different volume that DI takes into account. These results could suggest to Scandidos some changes in the software before its clinical implementation.

Quantification and Assessment of Skin Dose in VMAT and Tomotherapy: a Comparative Study using In vivo Dosimeter

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Prospective/Objective: This study aimed to evaluate the precision and accuracy of the MOSFET dosimeter in determining skin dose during Volumetric Modulated Arc Therapy (VMAT) and Tomotherapy treatments by comparing them with Gafchromic EBT3 film and the Tereatement Planning System (TPS). The research was conducted at the Instituto Oncologico de Veneto.

Materials and Methods: Thomson & Nielsen, Canada, produced the TN502RD MOSFET detectors. A set of tests was done on the mobile MOSFETs to see how accurate, repeatable, and angle-dependent they were. We were measuring the surface dose in a 6 MV beam on the TrueBeam machine and TomoTherapy. Measurements were performed on a RANDO antropormorphic model simulating head and neck cancer and breast cancer. Treatment plans were generated using the Eclipse treatment planning system for TrueBeam and Raystation for Tomotherapy, adhering to clinical protocols. VMAT plans included two arcs for the head and neck, and for breast cases, two half arcs were employed. For patient-specific quality assurance, portal vision images and arc checks are conducted before taking measurements. This ensures that the positioning and setup align with the treatment plan and verifies the accuracy of the delivery system before actual dose measurements are taken. MOSFETs, along with small 4x4 cm^2 pieces of EBT3 films, were positioned identically on the RANDO phantom to facilitate a comprehensive comparison between them.

Results: The study examined average percentage dose differences in both in-field and out-of-field measurements. When measuring Tomotherapy in-field, MOSFET always shows a higher percentage dose (7.50%) than Gafchromic film. This could be a sign of a systematic bias. The negative percentage difference between MOSFET and TPS in the in-field setting suggests a tendency for TPS to overestimate doses compared to MOSFET (-6.53%). Out-of-field measurements in Tomotherapy show that MOSFET gives more accurate readings than Gafchromic film (4.25%), while TPS significantly overestimates (-3.38%). When we look at TrueBeam, the in-field measurements show that MOSFET readings are consistently higher than Gafchromic readings (13.22%), which could mean that the dose estimates are different. The positive percentage difference between MOSFET and TPS in the in-field setting suggests relatively good agreement between the two measurements (9.78%). However, in out-of-field measurements, MOSFET again shows higher readings than Gafchromic film (6.425%), and TPS exhibits a slight underestimation (1.32%) compared to MOSFET. A study by Rajesh A. Kinhikar [14] and ZHEN-YU QI [13] showed a difference of 20–12%.

Conclusion: After a comprehensive analysis of our data, it is clear that our MOSFET system demonstrates stability and reliability, signifying its robust performance. The consistently accurate measurements obtained through MOSFET play a crucial role in upholding the overall quality and safety of the radiation treatment process. This steadfastness emphasizes the suitability of the device for precise dose verification, further strengthening its integral role in preserving the integrity of radiotherapy treatments.

The use of Hyperthermia to Enhance Radiotherapy Treatments

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Prospective/Objective: Surgery and Radiotherapy are treatment of choice for early stage localized tumor lesions. However, recurrences and/or metastases can occur after incomplete eradication of the primary tumor and lead to acquired radio-resistant tumors, e.g. Hypoxic tumors. Combined radiotherapy and hyperthermia offer great potential for the successful treatment of radio-resistant tumors through thermo-radio-sensitization. The aim of this study was to see the dose escalation effect of hyperthermia on six soft tissue sarcoma patients treated with a preoperative radiotherapy with 25 fraction (2Gy/fr) (for five weeks) and hyperthermia once in a week. In addition we also evaluated local response to hyperthermia and radiotherapy as a preoperative regimen for STS from the post treatment assessment.

Materials and methods: External beam radiotherapy planning was done on a prescription dose of 50Gy in 25fractions using Eclipse v.15.1 TPS. A VMAT technique was used for the six STS patients using 6MV photon beam and evtaluated according to the internal protocol for OARs and limiting the hotspots to the targets. Then the hyperthermia treatment planning was done on Plan2heat software using temperature optimization method (T_{90}, T_{50} and T_{10}) limiting the hotspots to < 45^0C. The Linear Quadratic (LQ) model extended with temperature dependent LQ parameters $\alpha(T,t_{int})(Gy^{-1})$ and $\beta(T, t_{int})(Gy^{-2})$ was used to model the radio-sensitization by hyperthermia. For the LQ parameters of hypoxic volume Oxygen enhancement ratio was used to take in to account that it has a lower sensitivity than the GTV. MIM Maestro® was used to calculate the Equivalent Radiation Dose for the combined treatment and also used to evaluate the treatment outcome by comparing the pre and post K_{trans} maps extracted from Dynamic Contrast Enhanced(DCE) MRI.

Results: A model to quantify the effect of combined radiation therapy and hyperthermia in terms of equivalent dose distributions was presented. Then dose escalation effect of hyperthermia was evaluated by comparing the equivalent dose distribution (EQDRT) for radiotherapy treatment only with the EQDRHT for the combined treatment. From the comparisons it was found that the higher the achieved temperature is the higher its enhancement will be. For the GTV using T10 the enhancement ranges from 4.1Gy (with T10-41.90C) to 6.8Gy (with T10-43.60C) and for the hypoxic volume the enhancement was 5.3Gy to 6.5Gy. For the treatment outcome evaluation hypovascularized volume of the tumor is evaluated with the MIM software as a subvolume of the GTV, for the patient with pleomorphic liposarcoma it has seen an increase in volume (+27%-GTV, +114%-hypoxic, with 40% necrosis) after the treatment because of the histology of the tumor while for the other the GTV and hypoxic volume becomes reduced (-37% , -21%, with 90% necrosis).

Conclusion: Biological modelling provides relevant insight into the relationship between treatment parameters and expected EQD. It has been shown that for a higher enhancement effect temperatures higher than 410C should be applied in order to get a significant amount of equivalent dose from HT. The volumetric maps of Ktrans allowed us to observe important variations between pre- and post-treatment, and therefore the sequence of DCE-MRI was found to be a potentially useful tool in monitoring radio-hyperthermia treatment outcome.

Commissioning of An Elekta VersaHD Linear Accelerator in Pinnacle Treatment Planning System.

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Prospective/Objective: The commissioning of Radiotherapy Treatment Planning System (RTPS) is the most crucial parts of the whole planning process. Indeed, a thorough commissioning is mandatory to ensure an accurate correspondence of the delivered dose to the planned one. The purpose of this thesis was to implement a physical photon beam model for PINNACLE TPS and the electron beam model for RayStation TPS and to create a single physical model able to match the dose output of the three Clinical Elekta Linacs VERSA HD installed at the Radiotherapy Unit of San Bortolo Hospital. Software tests and algorithm validations were performed in order to verify inter-linacs matching of absolute dose and beam flatness for energies of 6FF MV, 6FFF MV, and 10FF MV. The aim was also to define dose characterization procedure for inter-comparison purposes for the three linacs to contribute to a better understanding of the accuracy of single physical model, and to establish a reliable tolerance test report process-based tolerance and action limits of our Elekta VersaHD linear accelerators according to TG-218.

Materials and methods: An Elekta VersaHD (Elekta VersaHD, Stockholm, Sweden) was commissioned, and photon energies of 6FF MV, 6FFF MV, and 10FF MV (profiles, percentage depth doses, and output factor) were acquired for field sizes of 0.6 x 0.6 cm^2 to 40 x 40 cm^2, for wedge fields in various sizes, including 3 x 3 cm2 (without reference detector), 5 x 5 cm^2, 10 x 10 cm^2, 20 x 20 cm^2, and 40 x 30 cm^2. For electron beams the electron cones (applicators of) 6 × 6 cm2, 10 × 10 cm^2, 14 × 14 cm^2, and 20 × 20 cm^2 were used. The data obtained for both electron and photon beams type using a three-dimensional water phantom at a 100 cm SSD, detectors of various types, including Microdiamonds (PTW 60019), Sun nuclear edge detectors, Farmer chambers (TM 30013), Semiflex chambers (TM 31010), pinpoint (PTW 31014), and Advanced Markus (TM-34045), were used, the Sun Nuclear ArcCHECK was used for gamma analysis.

Results: The PDD of 6FF MV was marginally lower than that of 6FFF MV beams at a depth of 10 cm. When compared to open fields, wedge filters considerably reduce machine output while increasing the percentage depth dose. The energy output factor with the flattening filter was higher than that of the flattened beams for field sizes greater than 10 x 10 cm^2, but lower for field sizes less than 10 x 10 cm^2. The pass-rate metrics of 2 mm/2%, 2 mm/3%, and 3 mm/3% with an acceptable threshold of 90% for a Seven VMAT plans simulated using the Unicum model were clinically acceptable for the VersaPOD and VersaHD machines.

Conclusion: The VersaHD linac commissioning data, including depth dose, beam profiles, output factor, and other dosimetric data, w measured, analyzed, and characterized systematically. Photon beam modelling has been done for Pinnacle TPS, whereas electron beam modeling has been done for RayStation.

Setup of a system for online in vivo Dosimetry in VMAT treatments

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Prospective/Objective: To secure the patient treatment quality many tools can be used. In this study, the impact of setup of a system for VMAT treatment was analyzed. The analysis was done on 16 treatment plans using a PTW Verisoft and EPIgray of DosiSoft software. Errors arising during VMAT treatment could cause sever injury to patient due to high radiation dose per single fraction; therefore giving priority for setup of the system we can reduce the risk of errors that could compromise treatment outcome.

Materials and methods: In order to determine the impact of shifts in positioning on a patient-like phantom, we deliberately introduced the following errors. Shift in isocenter of 5 mm and 20 mm in the lateral direction (Plan_L05 and Plan_L2 respectively), a shift of 10 mm and 20 mm in posterior direction (Plan_P1 and Plan_P2 respectively), and 20 mm shift in anterior direction (Plan_A2).

Moreover, in order to examine the sensitivity of the system for the change in size/shape or weight of the patient-like phantom, we introduced a bolus (Plan_B) with thickness 1 cm and area 15 x 15 cm^2 and in order to simulate and evaluate the impact of air bubble within the tissue we introduced a dedicated a 3 cm thick rotation unit chamber plate Farmer 0.3 cm^3 (Plan_Farmer) into the PTW OCTAVIUS 4D phantom

Results: From Plan_L2, Plan_P1, Plan_P2 and Plan_ A2, the expected dose difference (from Pinnacle TPS) were higher compared with DosiSoft. On the other hand, the dose deviation predicted from EPIgray of the DosiSoft for Plan_L2 are lower than the one predicted from the Pinnacle TPS. On the contrary for Plan-Farmer all evaluated structures have a deviation greater than 10%. This shows that EPID based EPIgray of DosiSoft is very sensitive to the change in the density by Farmer Chamber plate which mimics the presence of air bubble within tissues. When examining the gamma index analysis for both 6 MV and 6 MV FFF energies, the gamma analysis via VeriSoft between the Pinnacle TPS and the measured dose maps through PTW729 detector all plans except Plan_Farmer showed a dramatic drop on gamma passing rate relative to Plan_0. Here we can notice that the VeriSoft is not sensitive to air bubble simulated as the Farmer chamber plate, which inserted into the PTW OCTAVIUS phantom.

Conclusion: By combing the EPID based EPIgray of the DosiSoft with the existing PTW VeriSoft gamma analysis technique we can boost the safety of patient and we can offer a comprehensive patient specific quality assurance that can detect errors due to anatomical change, or due to air bubbles between tissues or slight increase on weight of the patient as well as patient positioning errors introduced in the isocenter shift.

Dose Optimization Process for Full-Spine Digital Radiography in the Pediatric Population Using Exposure Index

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Prospective/Objective: the study should cover in multiple beams radiogram the entire vertebral spine in AP and lateral projection. Often, the acquisition should be repeated during long-term evulation. Patients are normally pediatric. The cumulative dose and radiation risk are higher in comparison with other radiographies. The aim was to create a dose optimization process based on a weight of the patient protocol that allows to reduce dose and at the same time keeping a good image quality.

Materials and methods: We analyzed 132 patients: 75 females and 56 males. The ages covered were 3 to 17 years old. Studies were obtained on a Ysio Max Siemens system in the pediatric hospital Regina Margherita of Turin. The equipment created the image stitching multiple beam radiograms. Radiology information were extracted using PACS and the dose tracking system. The exposure index was used for the optimization process; in addition, we needed the weight of the patient and the mAs registered. To study exposure index variations, we analyzed images obtained from a homogeneous and an anthropomorphic phantom. To assess the image quality, four radiologists ranked a group of 20 clinical images obtained pre and optimization and we measured the SNR and CNR using Image J. To simulate organ doses and radiation risk, we used PCXMC 2.0, simulating patients whose ages were 5, 10, and 15 years old and we used a GAF chormic film to obtain beam geometry information for the simulation.

Results: The optimized protocols were classified according to the number of beam radiograms stitched, projection, and weight of the patient. Before the optimization, the exposure index presented high variation between each beam radiogram; after the optimization, this variation was reduced. The DAP mean value was reduced differently according to the protocol and the dispersion of DAP values was reduced more than 70%. Our study showed that the Exposure Index may vary by more than 30% depending on the clinical protocol set in the console. The radiologist's evaluation showed that the new protocols had good image quality. SNR measurements suggest a slightly lower quality of the thoracic vertebras in AP projection. Radiation dose and radiation risk were reduced by even more than 50% in most of the organs according for early ages.

Conclusion: The dose optimization process succeeded in reducing the dose organs and obtaining a good image quality in most of the anatomy components. Optimized protocol turned the Exposure Index and DAP into more predictable variables to be used in future dose optimization programs. We consider that the method of dose optimization presented in this research can be applied to any radiological examination performed with digital equipment. It is important to consider that the exposure index should not be the only indicator into; it is also essential to take into account DAP and the correct radiography technique.

Verification of Ethos CBCT-guided online adaptive radiotherapy for prostate cancer using Raystation hybrid DIR algorithm, ANACONDA

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Prospective/Objective: Radiotherapy plays a crucial role in managing localized prostate cancer, where the planning process involves utilizing a snapshot dataset of the patient's anatomy during simulation. However, anatomical changes can occur between and within fractions, necessitating adaptation strategies. This study aims to comprehensively analyze the dynamics of dose accumulation during the treatment localized of prostate cancer, utilizing both scheduled plans (SPs) (reference treatment plan recalculated on the daily anatomy) and adapted plans (APs) (reference treatment plan reoptimized to match the clinical directive) within the Ethos system, employing the Raystation ANACONDA DIR algorithm.

Materials and methods: Eight patients treated with Ethos oART (60Gy/20 fractions) were retrospectively selected. The initial reference treatment plan was generated based on the planning CT (pCT) using Ethos. Before treatment, cone beam CT (CBCT) images were obtained, and the pCT data was mapped onto the CBCT image, thus creating the synthetic CT (sCT). An artificial intelligence algorithm then identified the influencer organs (prostate, bladder, rectum, and seminal vesicle). Ethos' deformation algorithm utilized these influencer organs to guide the deformation of the CTV and PTV from the pCT to the CBCT image. SPs and APs were subsequently generated on the sCT.

Daily CBCT images, SPs, APs, and reference treatment plans were transferred to Raystation TPS. Rigid image registrations (RIRs) were executed between pCTs and sCTs, followed by the deformable image registrations (DIRs) using the influencer organs as controlling regions of interest (ROIs) for each fraction. The dose corresponding to the DIR was then deformed to the pCT, and a dose accumulation analysis was conducted for both scheduled and adapted plans across all patients. Evaluation metrics included the Dice similarity coefficient (DSC), mean distance to agreement (MDA), and the Jacobian determinant (JD).

Results: Results indicated favorable DIR metrics, with influencer organs mean DSC ranging from 0.89 to 0.98, and the MDA from 0.03 cm to 0.09 cm. JD values for prostate, bladder, rectum, and seminal vesicle ranged from 0.77 to 1.11. notably, AP demonstrated improved PTV coverage compared to SP. For D98% > 95%, 25% of the patients achieved an adapted mean of 94.65%, compared to 12.5% achieving a mean of 88.05% for the SP. For D95% > 95%, AP displayed enhanced PTV coverage, with 100% of the cohort attaining a mean of 97.16%, whereas 25% achieved 92.25% for SP. CTV coverage remained high in both plans, with mean values of 98.03% and 99.13% for SP and AP, respectively.

Although OARs met clinical goals in both plans, AP exhibited increase volumetric dose to OARs. Patient-specific results unveiled target coverage coincidence in four cases, while the remaining four showed a deviation of PTV coverage between Raystation and Ethos delivered dose accumulations, signifying the impact of anatomical changes during adaptation.

Conclusion: Ethos oART emerges as an appealing modality for intact prostate cancer treatment, offering satisfactory CTV and PTV coverage while safeguarding OARs. Potential improvements in PTV coverage could be achieved with enhanced patient preparation and increased clinical staff efficiency.

Acceptance and commissioning of a Philips Incisive CT

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Prospective/Objective: Acceptance testing of a CT is done when a new device has been installed or there was an upgrade to existing equipment. The objective of this study is to evaluate a Philips Incisive CT system recently installed at Desio Hospital, evaluating if the device is as delcared by the vendor, if up to standard with national and international guidelines and establishing benchmark data from acquisitions.

Materials and methods: The Philips Incisive CT system has a 72cm bore and 50 cm field of view detector array used for head, body, cardiac and vascular applications. RaySafe measurement system with two sensors were used: the CT sensor is a 100 mm pencil-ionization chamber which can calculate kV, mA and or mAs from the measured voltage and the survey sensor, which will be used for leakage measurements. Catphan 600 for performance characterization, PMMA head and body phantoms of 160 and 320 mm respectively used for CTDI measurements. Philips Head and Body system performance phantom has a head phantom 200 mm in diameter and the body phantom 300 mm in diameter. Physics layer is for slice thickness and impulse response. Head water layer for measuring noise, CT number and uniformity. The PE and LEXAN/Acrylic cylinders are used for measuring the CT number linearity. The body water layer is used to measure CT number, noise and uniformity. The values to be examined with CT sensor are CTDI in air, weighted CTDI, CTDI reproducibility and linearity vs mAs and CTDI accuracy. With the Philips phantom spatial resolution, noise, mean CT number and uniformity, and slice width were assessed. The survey sensor accounted for the leakage. Finally, tube modulation was evaluated with the use of a combination of head and body phantom.

Results: The values for CTDI in air, weighted CTDI, CTDI reproducibility and linearity vs mAs and CTDI accuracy were all in agreement with the established manufacturer reference values of less than 20%. The declared values on the console for CTDI and geometric efficiency reflected accurately what was measured and calculated by the medical physicist. The current modulation of the x-ray tube illustrates higher variation for the larger collimation. Average radiation dispersion was measured to be 0.1 mGy/h, below the established reference value of 1 mGy/h. The automatic systems check evaluated the mean CT number and uniformity, noise and spatial in which all parameters received a ‘Passed’ status showing the fell within the benchmark ranges stipulated by the International Electrotechnical Commission (IEC).

Conclusion: The Philips Incisive CT passing these examinations suggest that from a theoretical point of view the device is ready for clinical use. That there can be strong levels of diagnostic confidence and that images the device produces will be of minimal noise, which means high levels of spatial resolution allowing the practitioner to be able to better identify structures and pathologies. Resulting in safer and better-quality patient outcomes. The radiologists make the final decision on its efficacy in clinical practice.

Replanning of a proton therapy plan with photons: Analysis of a fast and effective method.

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Prospective/Objective: The aim of this study is to evaluate photon plans created as a backup to the main proton plan in the event of a breakdown of the proton cyclotron for up to 2 weeks. Backup plans are created using the volumetric modulated arc therapy (VMAT) technique for various areas of interest: brain, head-neck, column.

Materials and methods: Nine brain, head and neck (H&N), column VMAT plans for nine patients (3 patients for each case) were created, starting from clinical proton plans. Two tools within RayStation (version 12A) treatment planning system (TPS) were used: Fallback (FB) and autoplanning (AP) by Guided Planning Solution (GPS), which is a Monte Carlo and Collapses Cone-based TPS. Plan quality was evaluated by using dose metrics: V95%, V105%, D95 and limit dose to organs at risk (OAR) from prescription plan. Patient specific quality assurance (QA) was performed for one patient from each group case with gamma analysis.

Results: V95 dose coverage was achieved for half of all plans. Due to the proximity of the tumor to the primary OARs, the minimum dose coverage in V95(%) could not be achieved and a decision was made on the most achievable coverage while sparing most of the OAR for 4 patients. On one of the brain patients an additional optimization was performed, as a test for further improvement of the automatic plan quality. A reduction in dose to the primary OAR was achieved, with a small decrease in dose coverage for both methods. All gamma analysis carried out for patients passed the acceptable treatment limit of 90% with tolerance 3%/3mm. For further verification, tolerance of 2%/2mm was successfully tested; only in one brain case patient the gamma passing rate was lower than the limit.

Conclusion: Both FB and AP methods were effective in order to create a backup plan starting from the clinical proton plan for our sample of nine patients. FB is faster than AP, therefore it is more suitable when time is an issue. AP leads to a higher coverage of the PTV, compared to FB, if the OARs are not near to the target. Additional optimization is recommended in order to improve plan quality for both FB and AP, when OAR are in close proximity to the target. This requires an extra work of about 30 to 40 minutes.

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