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Geometric accuracy comparison between three different C-arm LINAC for Radiotherapy

Prospective/Objective: Radiation therapy requires clinical linear accelerators to be mechanically and dosimetrically calibrated to a high standard. One important quality assurance test is the Winston-Lutz test which localizes the radiation isocentre of the linac. The delivery accuracy of highly conformal dose distributions generated using IMRT is strictly related to geometry accuracy of collimator, gantry, and that have many degrees of freedom is directly affected by the quality of the alignment between the radiation beam and the mechanical axes of a linear accelerator. For this purpose, quality control (QC) guidelines recommend a tolerance of ±1 mm for the coincidence of the radiation and mechanical isocenters. Traditional QC methods for assessment of radiation and mechanical axes alignment (based on pointer alignment) are time consuming and complex tasks that provide limited accuracy. The purpose of this work is to evaluate and compare geometric accuracy for three different C-arm LINAC, analyzing the results of the Winston-Lutz test performed for each accelerator and also checking and comparing the isocenter accuracy of integrated imaging system.

Materials and methods: Study included two parts: one related to isocenter accuracy of integrated imaging systems (OBI and EPID: On Board Imaging System and External Portal Imaging System), and one related to radiation isocenter accuracy (Winston-Lutz test); both these parts are phantom based evaluation accomplished analyzing images realized in many different geometric conditions; for isocenter accuracy of integrated imaging systems, the Varian Marker Block Phantom, a plastic phantom has been used, this phantom contains one fiducial marker at the center and four other markers at known locations; for the Winston-Lutz test, the BrainLab Frameless SRS QA target pointer has been used. Both phantoms have been placed at LINACs isocenter according to the field light crosshair projections. Measurements were performed on three Varian machines: True Beam, DHX and C600 (in the last one there is only one imaging system: EPID).The images acquired were analyzed with the image-j free software or directly with the off-line review viewer included within the Treatment Planning System (TPS) in use (Aria/Eclipse vr-15.6 from Varian Medical System).

Results: We compare the mechanical performance between the LINACs and according with the international recommendation mostly from AAPM Reports 142 and 198, other than vendor specifications and tolerance, considering basic and stereotactic requirements, Obtained results were in the acceptable basic tolerance (2 mm) except for the oldest C600, currently used only for few palliative treatments a day; the newest True Beam LINAC showed the best mechanical performance according to both basic and stereotactic requirement (1 mm) and is currently used for this kind of treatment; the remaining DHX satisfied basic requirements but not strictly the stereotactic one, and is used mainly for standard fractionation treatments.

Conclusion: We have proposed an end-to-end IGRT test that accurately and rapidly meets the requirements of TG-142 and follows the workflow of clinical IGRT practice, analyzing separately imaging system and radiation isocenter accuracy. We propose these procedures like practical test with a recommendation to introduce this kind of quality evaluation especially for LINACs used for stereotactic treatments.

Commissioning of in vivo dosimetry using an Electronic Portal Imaging Device

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Prospective/Objective: To leverage the verification system in radiation therapy by implementing in vivo dosimetry measurements using an EPID to prospectively analyze the transit images generated during treatment and estimate the dose delivered using point backprojection.

Materials and methods: An amorphous Silicon (a-Si) electronic portal imaging device (EPID) iViewGT was used for the commissioning of EPID in vivo dosimetry (EIVD). The dose is reconstructed using backprojection of the EPID signal. The signal collected by the EPID from the radiation passing through the patient (transit condition) is converted into an image, which is corrected for noise and non-homogeneous gains in the EPID's pixels.The dose is reconstructed using the point backprojection formalism: using conversion factors of EPID signal to absolute dose at EPID level, the dose for non transit conditions at EPID level is then calculated with finite tissue maximum ratios (FTMR), the maximum dose at SAD level is further calculated by using the inverse squared distance relationship, and finally, the dose at the point of interest is calculated using TMR factors. The conversion factors and FTMR factors were acquired by a combination of EPID and chamber measurements in non-transit conditions and in transit conditions, for various field sizes and phantom's thickness. The dose is calculated at a point in the planning tomography provided by the TPS, in this case Monaco's 6.0

Results: A model for dose reconstruction from EPID images of 6 MV photons was built, which is capable of calculating the dose to the isocenter of an homogeneous phantom with an accuracy under 0.55% for open fields. The dose reconstruction was evaluated along the central axis in a clinical relevant range of (3 - 20) cm, and found to be under a 2.5% of relative deviation from the dose calculated using. Additionally, the dose outside the central axis was assessed, in a radius of 9 cm and in a radius of 6 cm; the dose reconstruction relative deviation was under 5.8% and 2.84% respectively. The RMSE was evaluated for all off-axis measurements, with a maximum value of 6.62 for a dose range of (61-480), measured at different depths.

Conclusion: EIVD commissioning process and daily set-up is rather simple and little time consuming, furthermore, it provides an efficient and accurate assessment that can be implemented in the routinely practice to detect errors that otherwise would not be detected by pre-treatment quality assurance verifications.

Clinical validation of an automatic image segmentation system based on deep learning for its integration in the head and neck radiotherapy workflow

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Prospective/Objective: Image segmentation of organs at risk (OAR) is a focal point of the radiotherapy planning (RT) workflow with implications on the overall quality of the radiotherapy process, including plan optimization/evaluation and dose delivery. Up to now, contouring requires large amount of human resources because it relies mainly on manual delineations which is time expensive and operator-dependent. Inter-intra-operator variability, lack of standardization are common issues of manual contouring. Automatic tools have the potential to address these flaws improving the efficiency of the procedure. The study aim was to validate the Raystation automatic image segmentation module based on Deep Learning (DL) via 3D-Convolutional Neural Network and U-Net architecture. The head and neck anatomical site (HN) was chosen for the purpose of validation with the following endpoints: a) to assess the quality of the automatic image segmentation through comparison with manual segmented ROIs from clinically delivered plans; b) to investigate the impact of the geometric uncertainties, originated from the mismatch between the automatic and manual contoured ROIs, on the overall plan quality in terms of target dose coverage and OARs

Materials and methods: CT planning datasets, including RT plans and RT structures, from a cohort of 24 HN patients, treated from 2018 until 2022 at the University Hospital of Novara, have been used. A total number of 496 manual segmented ROIs were available to generate the ground truth scenario used for the purpose of the DL auto-segmentation validation. The contours generated by the DL tool were compared to the reference ones by means of overlap metrics, the Dice Similarity Index (DSC), and distance metrics including Hausdorff Distance (HD), the 95th percentile of Hausdorff Distance (HD95) and Average Hausdorff Distance (AHD). The impact of OAR segmentation errors on dose distribution has been investigated evaluating the difference of the dose delivered to the targets and manually contoured OARs reoptimizing the original plan with the automatic contoured ROIs. Target coverage, maximum and mean dose differences have been computed for each structure. Linear generalized methods, logistic regression and ROC curves have been used to evaluate the relationship between the contour disagreement measured by AHD metrics and the dose increments to OARs.

Results: Good agreement was achieved for the majority of the segmented ROIs with DSC values higher than 0.75 and AHD comparable with the image voxel size (1x1x2 mm3). Moreover, our findings were in line with the literature benchmarks obtained from auto-segmentation challenges. HD95 highlighted significant discrepancies at the extremities of tubular organs due to low contrast images and failures depending from artifacts. AHD values > 2.5 mm were related to mean overdosages to OARs > 2.5 Gy. Target coverage was independent from the segmentation agreement.

Conclusion: The DL-based auto-segmentation was validated in the HN site: The agreement with the gold standard was within inter-operator variability. AHD was a valuable prognostic factor for plan dose distribution degradation originated by segmentation errors.

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Commissioning of modern Treatment Planning System (TPS) for nuclear medicine therapy using standardized virtual phantoms

Prospective/Objective: TPSs have been recently introduced to personalize the internal radiation therapy, unfortunately, there are no harmonization or guidelines on commissioning these tools. The aim of this study is to assess the discrepancies among three TPSs developed for radioembolization with 90Y in terms of volumes of interest (VOIs) and dose metrics, i.e., mean absorbed dose and Dose Volume Histograms (DVHs).

Materials and methods: We used five (i.e., two experimental and three virtual) phantoms imported within three TPSs (Dosisoft, MIM, and Simplicity) used for 90Y dosimetry. The experimental phantoms were acquired with SPECT/CT D670NM/CT (GE) and filled with 99mTc-pertechnetate. The virtual phantoms assuming to be filled with 90Y were generated by MATLAB script and saved into DICOM format. NEMA homogeneous and kernel phantoms contained the following VOIs: body, body-1cm, target-2cm and target-1cm. The anthropomorphic phantom included the whole body, liver, and hot and cold spheres. Each TPS extracted the volumes of VOIs in ml. Three methods were used for voxel-based dosimetry calculations within the TPSs: the local deposition method (LDM), the LDM with scaling for known injected activity (LDMwS), and the dose kernel convolution (DKC) method. Simplicity used only the LDM approach, while MIM used the LDMwS one. LDM and DKC were applied to the Dosisoft software. The calculated volumes and dose metrics were exported using the TPSs or manually in a few cases. All the Bland-Altman plots and statistical results were calculated using RStudio software.

Results: There were no differences in volumes of VOIs for kernel and homogeneous virtual phantoms when evaluated within the same TPS. Differences up to 5% between homogeneous virtual phantom and experimental one and trivial differences between anthropomorphic virtual and experimental one were found. The difference of the mean absorbed dose for Kernel Phantom obtained from different TPSs for the same VOI was up to 50%, while the absorbed dose range varied between 0 Gy to 75000 Gy. The range of the mean absorbed dose for homogenous phantom was between 3 to 5.1 Gy. Concerning the two anthropomorphic phantoms, the dose difference was up to 10 times for the cold sphere, where the absorbed dose range of virtual phantom was shifted 100 Gy higher than the experimental one. The DVHs were different for homogeneous and anthropomorphic (virtual and experimental) phantoms due to the image noise and likely the low resolution of the experimental images. Besides the kernel phantoms, the DVH was generated, assuming that the administered activity was located inside a voxel. The Bland-Altman plots showed discrepancies for each VOI volume up to 25% and 10% for homogeneous and anthropomorphic phantom, respectively. In addition, the Bland-Altman plots comparing the mean absorbed doses of VOIs showed discrepancies up to 20% for the virtual phantoms and up to 10% for the experimental phantoms.

Conclusion: Significant discrepancies in calculated absorbed mean doses were found using the investigated TPSs. Further investigations are recommended using other radionuclides and TPSs.

Evaluating the effect on Hounsfield Units reproducibility with different algorithms in a dedicated radiation therapy CT scanner and its effect in detectability and dose.

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Prospective/Objective: In a CT scan, Hounsfield Unit is proportional to the degree of x-ray attenuation and is allocated to each pixel to show the image representing the tissue's density. Currently, CT scanners provide several reconstruction algorithms to address specific issues during CT imaging.We aimed to assess the change of computerized tomography attenuation (Hounsfield unit-HU) for different materials of known electron density within a wide range, using these available post-processing algorithms. We considered different iterative algorithms for Metal Artifact Reduction (iMAR), used to reduce the metal artifact effect, and Direct Density algorithms used to perform the easy dose calculation from the HU values at one artificial-kV instead of many different original kV values. These algorithms are provided by the manufacturer at the installed Siemens Dual Energy Syngo CT.

Materials and methods: In this prospective study, the Gammex 467 phantom consists of a 33 cm diameter Solid Water disk approximating the size of an average pelvis (330 mm × 50mm ×H). The phantom was equipped with different tissue surrogate inserts and three different metal inserts of Aluminum, Titanium, and Steel. Image analysis was performed using Image J. Mean CT numbers and the standard deviation of the inserts were measured within the regions of interest (ROIs) in the inserts. The dose calculation was carried out in the Varian Treatment Planning System within the box plan with a cube digital phantom sized (20x20x20) and each field size 10x10.

Results: This study shows that for different iMAR algorithms (8 algorithms specific for 8 clinical situations metal implants), the HU variations have the same trend toward the electron density of different human tissue surrogates, but the amount of these differences is changing over the metal inserts used: in detail, it appears that the iMAR algorithms introduce an underestimation of the HU for low electron densities materials while an overestimation for high densities and also that these variations are more significant, in terms of CNR, as the density of the metal, that produces the artifact, is higher. In the scan without metal inserts, the iMAR algorithms don’t bring any significant difference which instead is highlighted with the metal inserts, showing that the amount of HU change is dependent on the strength of these inserts. For the study of the Direct Density algorithm the calculated dose difference using the artificial 120 kV compared to the actual 120 kV scan, is almost negligible for soft tissue but for tissue with a higher density, like bone, there is a difference within 3%

Conclusion: Thus, from this study we concluded that although the algorithms described are of undoubted utility, their effect can lead to differences in the “output” which can produce errors, to be considered especially in processes based on an automated quantitative image evaluation or dose calculation based on tissue characterization.

A **systematic approach to identify the optimal input parameters of Personalized Planning.**

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Prospective/Objective: The main objective of the work is to evaluate the impact of different parameters in the new Pinnacle Evolution (version 16.4.3) by comparing it with their respective clinically accepted reference treatment plans. The plans were assessed according to the dosimetric parameters and monitor units.

Materials and methods: Two different clinical cases, i.e., prostate and head & neck, were treated with volumetric modulated arc therapy. Thirty-three plans were optimized for each clinical case: the clinically accepted reference plans were generated using specific plan parameters derived based on feasibility dose-volume histogram (FDVH) in PlanIQ. For each case, a reference plan was saved as a treatment technique, and before optimization, a single plan parameter was changed to determine its effect on the dose distribution and on the monitor unit amount. The plans were assessed according to the monitor units, dose metrics (i.e., dose volume criteria & DVHs) of both organs at risk (OARs) and Planning Target Volumes (PTVs). The evaluated OARs were the rectum and bladder for the prostate plan and the right parotid, lips and spinal cord for the head and neck plan.

Results: The conversion cycle adjusted to “10” and refinement cycles to “2” and “3” have produced a better plan quality with target coverage met and OARs sparing. Adjusting control MLC modulation to “Yes” spares OARs. Modulation amount parameter adjusted to “very high”, results in fewer monitor units (i.e., 681.2, 709, 743.9, and 699.5, MU for very high, high, medium, and low, respectively). “SRS/SBRT mode”, was effective for head and neck with both OARs sparing and target coverage met. For prostate, only the rectum and bladder mean dose was reduced with “standard fraction mode” compared to “SRS/SBRT mode”. Match target coverage adjusted to “No” showed a significant dose increase for targets and OARs mean dose and dose-volume criteria of both cases. For head and neck “weighting balance” parameter adjusted to “20” produced a better plan with OARs sparing and fewer monitor units (708.9 MUs compared 681.2 MUs). For prostate, weighting balance adjusted to “-20” produced a better plan with target coverage met and fewer monitor units of 977.2 MUs. For prostate target transition falloff rate adjusted to “30” or “40” have produced a better plan with fewer monitor units of 997.2 and 977.6 MUs, respectively. For head and neck target transition set to “40” spared right parotid and with fewer monitor units of 681.2 MUs. Target edge weight adjusted to “2” demonstrated to be the best choice for prostate and head and neck for OARs sparing.

Conclusion: The results indicate that parameter selection in Personalized Planning plays a vital role in improving the quality of treatment plans. It is concluded from the results that the dose variations with the change of input parameters are significant. The impact is greatest on the rectum, and right parotid mean dose of prostate and head & neck, respectively.

Implementation of Code of Practice for Quality Assurance Program in High Dose Rate Brachytherapy with Ir-192 source

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Prospective/Objective: To develop and implement the code of practice for Quality Assurance (QA) program in Brachytherapy (BT) with Ir-192 source. Because of the existence of variable BT equipment, AAPM TG-56 recommended each clinic to develop a dedicated QA program that suites its brachytherapy machine. In this thesis work, the code of practice for QA was written and implemented at Modena University Hospital aiming to assure accurate operation of BT equipment with a major focus on security controls, geometrical and dosimetrical measurements and to verify safety conditions for radiation protection purposes as required by national regulations. Multichannel applicators were commissioned to establish its baseline operating performance.

Materials and methods: Following the guidelines (IAEA TECDOC-1274, AAPM TG56, and GEC-ESTRO booklet-8), the code of practice for QA in BT was developed for microSelectron HDR-V3 unit and OnCentra treatment plan system (TPS). Transfer tubes, well type chamber, electrometer, Gafchromic films, check ruler, set of applicators and film scanner were used for source calibration and for commissioning of Multichannel applicator. For radiation protection purposes, a calibrated Automess (6150 Ad-B) was employed to verify the existing shielding and to check the leakage radiation. An end-to-end test was performed by using Gafchromic films that were placed within Multichannel applicator in a solid PMMA water equivalent phantom. By means of 2D-gamma analysis, films dose maps were compared to RTDoses from the OnCentra TPS after being loaded into PTW-Verisoft software.

Results: The results from the source calibration showed optimal agreement between the measured air kerma rate (source strength) and the value of source certificate with a difference of 1.82% and the measured source positions were within ±0.2 mm on average from the expected positions. The radiation protection results were in agreement with recommended limits, and the highest annual equivalence dose rate evaluated was 0.154 mSv/year in controlled areas. Results of first source positions for all Multichannel transfer tubes and needles evaluated were in agreement with respect to declared values, with a maximum difference of ±0.5 mm. Gamma passing rate calculated between film and RTDose maps was 100% for the intrauterine VT and was 91.8% for needle-10, with 3%/3mm criteria.

Conclusion: Results showed that the status of the machine and its components ensured an acceptable clinical outcome. The deviation in source activity was less than the recommended tolerance limit 5%, uncertainties in source positions are less than 1mm and agreed with the GEC ESTRO (2004) recommendations. The walls bunker shielding were still suitable according to national regulations. The end-to-end results guarantee the correct dose delivery to patient.

Impact of data-driven respiratory gating algorithm on small lesions in PET/CT imaging.

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Prospective/Objective: Respiratory motion induces artifacts in PET/CT imaging that may introduce significant image distortion, and an important cause of diagnostic uncertainty, particularly for lesions located in the lung/diaphragm interface.Our primary objective was to assess the effects of a data-driven respiratory gating (DDG) algorithm on lesion maximum standardized uptake value (SUVmax) and volume for small lesions with low and moderately low target-to-background ratios.

Materials and methods: We used the QUASARTM Programmable Respiratory Motion Phantom, which is designed to move cylindrical inserts in the superior-inferior direction within a torso shaped acrylic oval varying both speed and amplitudes.We have built an insert compatible with Quasar phantom motion platform that allows the simulation of the background. The insert was filled with water to simulate the liver density (~1.07 g/cm3) and with water and polystyrene beads to mimic lung density (~ 0.3 g/cm3). We placed inside the insert a glass sphere with 13 mm inner diameter to represent a small tumor. Both insert and sphere were filled with 18F-FDG solutions of different concentrations to attain different target-to-background ratios. For the acquisitions, we used the Whole Body PET/CT protocol that includes the Q.Static acquisition mode, in which an automated motion correction technique is integrated. DDG-PET data were derived from a portion of the total PET data (~50%) in the end-expiration (EE) phase at 30% offset from the end-inspiration (EI) phase of each respiratory cycle. We investigated effects of data-driven respiratory gating algorithm on lesion maximum standardized uptake value (SUVmax) and volume by comparing DDG-PET images and non-gated PET images, both reconstructed with two available algorithms: VUE Point FX (VP) and Q.Clear (QC).

Results: For the 3:1 target-to-background ratio (TBR), the motion correction with DDG PET increased the lesion SUVmax by the average of 25 ± 13% for VP and 26 ± 17% for QC. The lesion volume decreased by 35 ± 15% for VP and 31 ± 36% for QC. For 3:1 TBR lung case, the motion correction with DDG PET increased the lesion SUVmax by the average of 26 ± 10% for VP and 27 ± 17% for QC. The lesion volume decreased by 31 ± 40% for VP and 27 ± 32% for QC. In these cases, the average was done over 4, 6, 8 and 10 mm motion amplitudes. For the 4:1 TBR, the motion correction with DDG-PET increased the lesion SUVmax by the average of 28 ± 12% for VP and 33 ± 12% for QC. The lesion volume decreased by 39 ± 13% for VP and 39 ± 10% for QC. In this case the average was done over 4, 6, 8, 10, 12 and 15 mm motion amplitudes.

Conclusion: Application of DDG was found to significantly increase the lesion SUVmax and decrease its volume with respect to non-gated images, by mitigating the blurring effects of respiratory motion, and to give more accurate representations of uptake as well.

aaImage quantification and analysis of SPECT DaTscanTM examinations of patients with suspected Parkinson's disease through two 3-D automatic tools

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Prospective/Objective: This work reports a head-to-head comparison on the quantification of two software, BasGanV2 and Datquant®, of DaTscanTM radio-tracer uptake in brain striatum regions through the correlation between quantification metrics, and the decision of these metrics towards isolating patients with Parkinson's disease (PD) from the sample with visual reading by the physician (the gold standard, GS). The metrics include specific binding ratio (SBR), putamen-to-caudate ratio (PCR), caudate-to-putamen ratio (CPR) and asymmetry indices (AI).

Materials and methods: The study analyzed 112 patients who underwent brain DAT (Dopamine active Transporter) SPECT imaging with DaTscanTM for a suspected parkinsonism. The post-processing of brain DAT images was performed using the two software for quantification purpose. The Bland-Altman analysis was used to reveal the mean bias between the two methods, while for instance the areas under ROC (receiver operating characteristic) curves (AUCs) of SBR values were utilized to measure the diagnostic accuracy of the metrics.

Results: The study found a significant correlation between the two software for each semi-quantification parameter. The correlation coefficients, r, ranges from 0.684 to 0.962. Among others, a strong correlation was observed for SBR values with, r = 0.962, 0.9477, 0.9474, 0.946, respectively, for left putamen, left caudate, right caudate and right putamen SBRs. Furthermore, with BasGanV2 quantification, out of 112 patients, 74 (66.07 %) had PD and 38 (33.93 %) were normal, while with Datquant®, 68 patients (60.7 %) were positive to PD and 44 (39.3 %) were healthy patients. The GS confirmed PD in 64 patients (57.14 %) and 48 patients (42.86 %) were found normal. The PD diagnostic agreements between BasGanV2 and Datquant® software and doctor's decision, were, respectively, 85.71 % and 83.92 %. In addition, AUCs showed that the two tools offer a PD diagnosis to about 95.20-99.99 %.

Conclusion: All semi-quantitative metrics showed a significant correlation between Datquant® and BasGanV2 and higher values of AUCs support the accurate PD diagnosis with these tools. Along with this, the mean bias observed between the two methods, hints out that none of them is preferred over the other.

Dosimetric commissioning of VMAT treatment on a Linac after a major MLC upgrade

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Prospective/Objective: The complex dose distributions of the VMAT technique increase the importance of accurate beam data measurements and review in the commissioning process. In this work, a Synergy linac, containing a beam modulator MLC collimator gets upgraded with an Agility MLC. The aim of the present study is focused on the dosimetric commissioning and validation of the updated linac for 6MV photon beams and VMAT treatments as well as describing general concepts, regarding beam modeling in the TPS and dose verification before clinical use.

Materials and methods: For the dosimetric measurements of acquiring beam data of a Monte Carlo based TPS, "Monaco", a watertank was used, which can measure the dose distribution in all directions to obtain PDDs and profiles accurately, with the advantage that water mimics the radiation properties of human tissue. Beam modeling was done with special test beams, analyzing different parameters of the MLC's that can be optimized inside the TPS. These test beams were measured on a cylindrical phantom, a Delta4 WiFi, offering the analysis of 3D dose distributions. VMAT plans were calculated and optimized following the AAPM TG119 for dose prescriptions, planning objectives and dose verification. AAPM TG119 report presents guidelines from a dosimetric study, to facilitate and ensure the accuracy after commissioning processes for modulated techniques, proposing mock test plans with dedicated phantoms. An on board Epid and two cylindrical phantoms; the Delta4- and Matrix phantom were used for comparison of 2D/3D dose distributions, the Matrix was used for 1D single point absolute dose verification. The comparison of measured and calculated dose was done by using a global gamma criteria of 3%/3mm as well as 2%/2mm (10% cut of). Confidence limits (CL) were generated and compared with the TG119. Lastly, 20 clinical plans were irradiated with the updated linac, using the Delta4 and Epid for comparison of dose distributions. The interchanging between this linac and two other linacs with the same dosimetry was also tested.

Results: Measurements for verification of the TPS dosimetric model received from the manufacturer concluded that it was necessary to modify the Leaf Groove Width from 0 to 1mm, to obtain an acceptable match between calculated and measured dose distribution. The overall passing rate for the TG119 mock plans, using the 3%/3mm gamma criteria for the Delta4 and Epid were 99.8%±0.12 (CL 0.47) and 97.4%±0.24 (CL 3.1), respectively, and with the 2%/2mm gamma, they were 97.5%±1.3 and 95.6%±0.49. While measuring the 20 clinical plans with the Delta4 and Epid, at the reference QA criterion of 3%/3mm, the gamma passing rates were all above 97.7% and 94.7%, respectively. When the tolerances became stricter with 2%/2mm, the gamma passing rates were all above 90 % for the Delta4 and 85.1% for the Epid, which is still considered acceptable. The absolute dose measurements with the Matrix resulted in a mean difference of 1.3% with a standard deviation of 1.23. The interchanging between linacs showed differences in gamma passing rates ≤ 0.3%.

Conclusion: TG119 methodology and recommendations have successfully been used to evaluate commissioning accuracy of VMAT plans and the obtained data were found within the limits of TG119. After completing all the measurements described in this work and being satisfied with the results, this upgraded linac was ready to be used clinically.

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Dosimetric Comparison of 3-Dimensional Conformal Radio-Therapy (3D-CRT), Volumetric Modulated Arc Therapy (VMAT), and Hybrid Volumetric Modulated Arc Therapy (H-VMAT) Techniques for Left Breast Cancer

Prospective/Objective: The aim of this study was to evaluate 3D-CRT, VMAT and Hybrid Volumetric Modulated Arc Therapy (H-VMAT) techniques for left breast cancer treatments. Dose homogeneity and conformity of the Planning Target Volume (PTV) and organs at risk (OAR) sparing were evaluated, as well as the plan's robustness against rigid patient shifts. The study was conducted in Azienda Ospedaliero Universitaria delle Marche (Ancona, Italy).

Materials and methods: We considered patients who underwent left-breast after-surgery radiation therapy with a dose of 40.05 Gy in 15 fractions prescribed to the whole breast, with no boost to the surgical bed. Seven patients treated with 3D-CRT plans were selected with the following criteria: D2% < 107% and D98% > 90% for PTV, V16Gy < 20% for left lung, V8Gy < 20% for heart and Dmean < 20Gy for the Left Anterior Descending artery (LAD). Concurrent VMAT plans (Eclipse RapidArc®) were optimized imposing OARs constraints equal to the 3D outcomes. Were used three different treatment techniques, Two tangential opposing open fields were used for 3D-CRT with field in field, three half arcs were used for VMAT, and for the H-VMAT (H-VMAT1a and H-VMAT2a), two tangential opposing open fields were used for the 3D-CRT part 80% of prescription, and one and two half arcs were used for the VMAT part with 20% of prescription. This should be finished for future clinical implementation of Breast cancer treatment. Moreover, only setup uncertainties in the ±5 LL direction were included for evaluating the plan's robustness.

Results: Homogeneity Index (HI) mean value for H-VMAT 2a (0.07±0.01) was improved respect to H-VMAT 1a (0.10±0.02), VMAT (0.10±0.02) and 3D-CRT (0.12±0.01) with a p-value p<0.03 among all techniques. No statistical difference was found between H-VMAT 1a and VMAT (p=0.8).As expected, VMAT provided the highest conformity to target, with a Conformal Number (CN) mean value of 0.89±0.01 for the isodose 95%. Conformity for both H-VMAT solutions was characterized by a mean value of 0.86±0.04, which was very close to VMAT outcome. No statistical difference was found between H-VMAT with one and two arcs (p=0.8). CN of 3D-CRT was 0.75±0.04. Left Lung V16Gy for VMAT (10.1±4.1 %), H-VMAT 1a (12.3±5.7 %) and H-VMAT 2a (12.0±5.7 %) showed a negligible difference with 3D-CRT outcome (0.09<p<0.22). In the low dose region of the DVH, a decrease of the irradiated volume V4Gy was observed for H-VMAT 1a (34.9±5.9 %) and H-VMAT 2a (33.4±5.2 %) respect to VMAT (39.7±7.0 %). Contralateral lung and breast received an evident dosimetric advantage with the use of Hybrid techniques respect to VMAT plans. We found a mean dose value of 298±22, 49±13 and 87±13 cGy for right lung and 358±35, 80±25 and 143±23 cGy for right breast, using VMAT, HVMAT 1a and HVMAT 2a, respectively. Right lung low dose bath was characterised with V5Gy values never exceeding 1.2% for all H-VMAT plans, against a mean value of 16.2±5.2 % for VMAT. Compared to 3D-CRT dosimetry, H-VMAT outcomes for contralateral lung and breast should be a negligible source of clinical concern, especially if one arc is used. Mean dose value of heart in 3D-CRT technique was (124.93±34.25 cGy), in VMAT technique (292.89±55.58 cGy), H-VMAT 1a (185.14±48.60 cGy) and H-VMAT 2a (182.99±45.28 cGy) techniques. No statistical difference was found between H-VMAT 1a and H-VMAT 2a (p=0.7).LAD mean dose did not show an appreciable difference among all techniques, with an overall mean value of 540±328 cGy. In order to evaluated robustness against setup errors, a shift of ±5mm (IEC1217) in Latero-

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Lateral direction was applied to isocenter. The CTV volumes covered by near minimum and near maximum dose, D98% and D2% respectively, were used for dosimetric evaluation. D2% and D98% values did not change significantly for shifted plans among all techniques ($0.33<p<0.64$).

Conclusion: Basing on our patient selection, we demonstrated that H-VMAT technique was a good trade-off between "pure" VMAT and 3D-CRT plans for left breast treatment. HVMAT provided good homogeneity and conformity to target while preserving heart, contralateral breast and lung. Furthermore, it had a limited impact on planning activity since it did not required any "skin flash" management to ensure robustness against moderate patient shifts.