CHAPTER 6

Commissioning and quality assurance of the CMS XIO radiotherapy treatment planning system for external beam photons

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6.1. Introduction:

This paper presents details of the commissioning and quality assurance of XIO treatment planning system at our institute. Small variations in radiation doses can cause significant changes in clinical outcome; the calculation accuracy is a major factor in the success or failure of a cancer treatment course. Computerized treatment planning systems (TPSs) are used in external beam radiotherapy to generate beam shapes and dose distributions with the intent to maximize tumor control and minimize normal tissue complications. We used CMS, XIO 3-D Treatment planning system. The XIO treatment planning system (Computerized Medical Services, USA) for three-dimensional (3D) conformal radiotherapy has been used throughout the world for several years. It is compatible with Varian (Varian Associates, Palo Alto, CA), Siemens (Erlangen, Germany) linear accelerators and also with Elekta (Crawley, UK) machines.¹

Young physicists and any user can get benefit from the approach taken for the Commissioning process. The Commissioning and quality assurance of the CMS XIO radiotherapy treatment planning system involves many steps, beginning from beam data acquisition and entry into the computerized TPS, through patient data acquisition, to treatment plan generation and the final transfer of data to the treatment machine and quality assurance of TPS.² Reports on the commissioning of TPS process is reported by several authors.³⁻⁶ Medical physicist is responsible for the overall integrity of the computerized TPS to accurately and reliably produce dose distributions and associated calculations for external beam radiotherapy.
The treatment planning system is commissioned for Elekta Synergy (4, 6, and 15 MV) and Siemens Primus Plus (6MV and 15MV) linear accelerators. The treatment planning system is connected to Elekta synergy machine directly with the help of Elekta desktop pro where as it is connected via Lantis network to Siemens Primus plus machine. The treatment prescriptions can be sent directly from the planning system to the treatment units with the help of these technologies.

6.2. Methods and Materials:

Linear accelerator geometry parameters, mass attenuation materials, starting wedge coordinates, and published data tables are collected before going for beam modeling. Central processing unit (CPU), Memory, RAM, graphics display, output devices, network and archiving devices are the most important parts in Treatment planning system. The system should have capability to upgrade in future. System compatibility to communicate linac, and data import from beam acquisition systems must be considered.

6.2.1 Photon beam modeling

6.2.1.1 Machine data

The following data are collected before transferring the beam data from Beam acquisition system (Scanditronix, Omnipro) to XIO planning system. Limitations of the accelerator (target to collimator and tray distances, asym jaws, MLC type, etc.), Wedge specific data are collected (e.g., material alloy, design and mounting specifications, maximum field size limits, linear attenuation coefficient, etc.).
The gantry, table and collimator rotation conventions taken accurately. For the IMRT field's data regarding the maximum leaf speed, characteristics of the maximum rise in the beam-on time, information on maximum dose rates and maximum leaf over travel etc are taken for TPS. Information regarding the distance from the cone to the nominal SSD, as well as the external dimensions of the electron cone fed into the TPS, so as to avoid potential patient-machine collisions. Geometry of the radiation detector (typically ionization chambers or diodes) is considered to get the accurate values.

6.2.1.2 Beam data acquisition and entry

Photon beam data are measured using an energy-compensated p-type photon diode detector (Scanditronix, Uppsala, Sweden) in conjunction with a water tank and electrometer (Wellhöfer, Schwarzenbruck, Germany). Results using the diode are checked for a variety of field sizes against those obtained using a 0.13 cm$^3$ ionization chamber (Wellhöfer, Schwarzenbruck, Germany). Since the agreement is good (see Results) the diode is used for all subsequent profile and depth dose measurements.

The following data obtained to load into the XIO planning system. These data got by Radiation field analyzer, diodes and various ionization chambers. The measured data are imported into XIO using the import facilities provided from Omnipro system (scanditronix wellhofer, USA) threw RS-232 Cable. The XIO approach is then to use the measured data to generate a model of the accelerator head, from which dose in any arbitrary situation could be calculated. The principal elements of the beam model are followed as below.
6.2.1.3 Photon Beam (Scanning):

Diagonal Profile Scans for the largest open field from 0.5 cm to 30 cm depth are taken. Half field scans are done for few profiles and mirrored. Open Field PDDs (on CAX) from 3x3 cm$^2$ to 40x40 cm$^2$ field sizes are obtained up to the depth of 40 cm. Open Field Aligned Profile Scans for the square field sizes 5x5 cm$^2$ to 30x30 cm$^2$ for the depths $d_{max}$ 5, 10, 20 and 30 cm is taken.

Wedge Field PDDs (on CAX) for the square field sizes 5x5, 10x10, and 20x20 until the depth of 30 cm and Wedged Field Aligned Profile Scans in the wedged direction are taken for the depths ($d_{max}$, 5.0, 10.0, and 20.0 cm). Block Edge Profile Scans (20x20 collimator setting, blocked down to a 10 cm wide asymmetric port such that one edge is 7.5 cm from CAX and the other edge is 2.5 cm from CAX (at iso)) for the depths ($d_{max}$, 5.0, 10.0, and 20.0 cm) are taken with scan increment, 1 to 2 mm.

MLC Edge Profile Scans are taken for 20x20 collimator setting with a 10 cm wide asymmetric MLC port with one leaf bank at 7.5 cm from CAX and the other leaf bank at 2.5 cm from CAX (at iso) for the depths ($d_{max}$, 5.0, 10.0, and 20.0 cm).

6.2.1.4 Photon beam data—non-scanning

Total Scatter Factors (TSCF's or Scp) are measured with the chamber at isocenter for the collimator settings of 4x4, 5x5, 6x6, 8x8, 10x10, 12x12, 15x15, 20x20, 25x25, 30x30, 35x35, 40x40. Absolute output is taken for the reference field size, measured at the reference depth employing the same setup as used to collect the TSCFs. Collimator Factors (or Sc) measured with the chamber at isocenter for the collimator settings of 4x4, 5x5, 6x6, 8x8, 10x10, 12x12, 15x15, 20x20, 25x25, 30x30, 35x35, 40x40. Phantom Scatter Correction Factors (PSCF's or Sp) or BSF's are calculated. Physical Wedge Transmission
Factors (WF) are measured with an SSD setup (SSD = isocenter distance) and the chamber at dref depth. Standard external physical wedges data is taken for collimator settings 5x5, 10x10, 15x15, 20x20, (max wedged square field size.). For motorized internal physical wedge (Elekta, GE) data obtained for collimator settings of 5x5, 7x7, 10x10, 12x12, 15x15, 20x20, and max. Wedged square field size).

6.2.1.5 IMRT Specific data

In addition to the data specified above the following data is taken for IMRT beam modeling. A. PDDs for 2x2 and 3x3 collimator formed fields. B. Profile(s) for an MLC formed field size of 2x10. The 2 cm dimension should be formed by the MLC and is scanned across the 2 cm direction. For those machines with collimator or back-up jaws (Varian/Elekta), these jaws should be 10cm wide (i.e. 10x10 collimator setting). These data is collected with film at the depth of 10 cm, then properly converted to dose with an H&D curve, and scanned along a line that does not contain interleaf leakage. It provides the hardcopy plots of profile data. MLC transmission and Collimator transmissions are measured with miniphantom (3cm diameter and 40cm length). Beam data for modeling are collected at a source-to-surface distance (SSD) of 90 cm 100cm and 110cm for the triple energy accelerators.

Beam data is smoothed and renormalized both following measurement and prior to data entry into the treatment planning computer. An energy spectrum generated at the source that is described by relative weights of discrete energies of the photons. This spectrum is determined from the depth dose characteristics of the measured data. TPR or TAR tables are generated with XIO system itself from PDD’S. OCD is modified where ever it needed. PSCF is extrapolated as appropriate for Clarkson modeling. FFT Convolution spectra for small wedge PDD is fitted and also for other wedge PDDs. Spectra is then adjusted for
small open field PDD'S. Off-Axis spectra are adjusted for large fields. Large wedged field PDDs and Profiles are checked. Wedge coordinates are adjusted for coarse agreement. Spectra also adjusted as required for the best solution to open and wedge field PDDs. Convolution wedges are fine tuned (on-screen fits). Checked whether the open field and wedged field PDDs meet the modeling specifications.

6.2.2 Electron beam modeling:

The following data is collected before transferring the electron beam data from omnipro to XIO planning system.

Electron beam data (scanning): Central Axis Depth Dose Scans (Open Field for each Cone) and Open Field Aligned Profile Scans.

Electron beam data (non-scanning): Absolute output factors and their corresponding measurement depths for each Cone and Effective SSD (Khan’s method) per cone, per energy.

Beam measurement for electrons is more difficult than for photons because of the continuously decreasing energy of the beam with depth. Electron beam data measured with ionization chambers must be first converted to dose with an appropriate method, typically using a look-up table of stopping power ratios. Measurements with silicon diodes are often considered to be tissue equivalent and give a reading directly proportional to dose.

6.2.3 CT-to-Electron density conversion: Medtech Benchmark phantom (Medtech, USA) is used to generate CT-to-Electron density tables at the 120 kV CT voltages (Siemens, Somatom, USA). This phantom consists of lung, air, bone inserts. These CT-to-density tables are used for all subsequent testing. CT quality assurance phantom Catphan phantom
Catphan phantom 503 housing is made of solid-cast material made of carbon, oxygen, nitrogen with electron density of 1.04gm/cc. This phantom is having 4 sections with different test modules CTP401, CTP528, CTP515 and CTP486 to measure phantom position, alignment, spatial linearity, size of pixel, contrast resolution and spatial uniformity. This phantom is used for periodical verification of the CT-to-density tables.

TPS require accurate information concerning the geometry and composition of linac beam line components such as the waveguide exit window, target, flattening filter, scattering foil, transmission ionization chamber, jaws, MLC, blocks and trays, and any other items the electron or photon beam is likely to encounter.

Beam data acquired from a linac may be entered manually or threw cable RS-232. Attention must be paid to the file format. File headers contain formatting data concerning the direction of measurement, SSD, energy, field size and other relevant parameters. Special attention must be paid to these labels to ensure that they are properly passed to the TPS.

6.2.4 Automodelling

XIO generates beam parameters automatically according to measured data. Machines are created manually for each energy. For each combination of linear accelerator and beam energy, separate models are produced for open and wedged fields. Energy spectrum and electron contamination characteristics can be adjusted simultaneously. The process fine tuning is also run, to improve the cross-beam profiles for a range of field sizes and PDD’s. Output factors are then computed.
6.2.5 Beam data validation: Validation of the beam should be the final step in the beam modeling process. MLC and Block Edge Penumbra profiles are imported from dosimetry system. Block/MLC parameters in SFM for Clarkson and Convolutions are edited. Re-Validation and then re-calculation are done in Teletherapy planning mode. Continued the process until satisfactory agreement is achieved. These modeling steps are then repeated for the next MachineID.

6.2.6 Patient data

The patient image data is transferred to the TPS via the DICOM 3 (Digital Imaging and Communications in Medicine) format from CT. For accurate dose calculation, the CT to ED Conversion and scattering power ratios are taken. Contouring is done by using auto segmentation, auto threshold and manual contouring. Targets are marked with the help of ICRU Report No. 50 and the ICRU Report No. 62. Patient anatomy may be displayed using the Beams Eye View (BEV) capability of the TPS. Beams can also arrange with the help of BEV. Treatment plans are evaluated using Dose Volume Histograms.

6.2.7 Quality Assurance

A. Comparison of planned and delivered dose for simulated clinical cases using Medtech-IMRT benchmark phantom.

To test the overall performance of the treatment planning system, two treatment plans are created for an IMRT-Medtech phantom, the plans are delivered, and the planned and measured dose distributions compared. The present study is carried out for two simulated clinical cases: a pelvic (prostate) treatment and a brain (astrocytoma) treatment.
IMRT-Medtech phantom is CT scanned and simulated clinical target volumes are delineated using CMSXIO system. A 3D margin of 10 mm is applied to the prostate volume and a 3D margin of 30 mm is applied to the brain tumor (astrocytoma) volume, to provide planning target volumes. The prostate case is then planned using three 6 MV fields, with gantry angles of 45, 126, 180, 230 and 315. The five fields are conformally shaped to the beam’s eye view (BEV) of the planning target volume, with a margin of 5 mm allowed for penumbra. The brain case is planned using five 6 MV fields, with gantry angles of 45°, 90°, 135°, 275 and 315°. Five mm margin being allowed between the field edge and the BEV of the planning target volume. 0.6cc ionization chamber and EDR2 films are used to verify the planned dose distributions.

B. Geometrical verification and the digitizer and plotter (printer) verification on Treatment planning system

Data verification entails a rigorous comparison between measured or input data and data produced by the TPS. AAPM TG 53 provides a detailed description of quality assurance tests that may be carried out by the clinical physicist. TPS performance is carried out with the help of AAPM TG53.

In Geometrical verification test the accuracy of the TPS to produce shielded regions is checked by blocks or apertures, performed by overlaying a hard copy.

In the digitizer and plotter (printer) verification test it is verified by using the digitizer to enter a contour of known dimensions and by comparing it with the final hard copy.

C. Asymmetric Jaws verification: Film is used to check this test. Commissioning tests will include fields using asymmetrical jaws. Jaw positions as calculated by the TPS are compared with film.
D. **Dose Calculations:** Calculations of rotational beams for both photons and electrons are compared with measured data.

E. **Compatibility between the CT scanner and the TPS:** A file transfer process is checked from CT to TPS. Dicom3.0 software performance is checked by sending data to TPS. The transfer of image data is checked by performing an analysis of the input data for a known configuration and density, such as a phantom, to detect any error in magnification, spatial coordinates, pixel values, scan size and matrix size.

F. **Output calibration:** Using CMS Phantom (40x40x40 cm³) Calibration setup condition is reproduce. Single beam is delivered with 10x 10 cm² field size and 100 MU is given. Checked that the system that it calculated 1cGy/MU at isocenter.

G. Compared the XiO MU calculations to independently determined MU calculations based on point dose measurements of dose rate, both on and off-axis, for symmetric open and wedged fields at 5 cm and 20 cm for all algorithms (conventional, superposition and fast super position algorithms).

H. **Quality assurance of digitally reconstructed radiographs:**

Attention is given to digitally reconstructed radiographs (DRRs) since these are to be used as the standard for verifying patient position. A simulated cuboidal water phantom with an off-centre cuboidal cavity of lung-equivalent density is digitized into the treatment planning system, together with planning target volume (PTV) and heterogeneity outlines. The principal dimensions of DRRs and BEVs of the phantom, with respect to the central axis of an applied field, are then measured and compared with manually calculated dimensions. The DRRs are then compared with BEVs for cardinal beam angles, together with several less regular angles. DRRs are also evaluated at several source-to-film distances. DRRs for a
conformally blocked brain plan and an MLC prostate plan are also compared with corresponding BEVs.

I. Quantitative per beam QA using the intensity modulation QA (IM QA) feature (Relative dose QA):
IM QA ASCII output files will be calculated automatically for any or all IMRT beams. The calculated IM QA output files contain the computed dose in a plane perpendicular to the beam at 100cm SSD and 5cm depth in an IMRT-Medtech phantom. The reported dose values are relative values. The dose along the weight point fanline is normalized to 100% and all other values are relative to that. Some values may be greater than 100%, some may be less, depending on the modulation and the placement of the weight point as shown in [Figure-1]. These files are generated and compared to planar, individual beam dose measurements made via EDR-2 film.

The output files are imported into the RIT software; the measured and calculated planes are normalized with respect to each other and the comparison of measured versus calculated doses performed for verification of relative dose agreement.

Figure-1: Comparison of single exposure from planning system to exposed film on RIT.
J. Quantitative composite or per beam QA using the QA plan and dose planes

features (Absolute dose QA)

This QA Plan used to do patient-specific IMRT QA. The IMRT Medtech phantom is used for measurements. Treatment’s beam geometries (e.g., five field prostate with original gantry angles placed on a Medtech phantom and calculated and measured for cumulative dose) are maintained while taking the reading with ionization chamber. The QA phantom is treated just like any other patient dataset. Point dose verification often find it appropriate to contour the active volume of the chamber as a structure and use the mean DVH dose to that structure when comparing measured to calculated. This is instead of simply comparing the doses to an interest point dose, which is a highly localized dose report and impossible for a chamber as large as a Farmer chamber to measure, unless the measurement occurs in a low dose gradient region.

K. Feature (non-dosimetric QA)

The Intensity/Relative Fluence map feature allowed us to generate a planar Intensity or fluence map ASCII text (.txt) files for each beam, or to view and print out graphical displays of the intensity or fluence maps for each beam. The print outs of intensity maps compared to the intensity maps produced by RIT software from scanned films to confirm delivery. The ASCII intensity map files are used to make numerical comparisons. This method is used to quickly, qualitatively verify the delivery.

L. Dose Profiles

This feature allows us to graphically analyze a group of dose points. Dose plane is imported from XIO to RIT for particular beam. This beam dose profile should be compared with dose profiles of exposed film. Film is exposed in IMRT Medtech phantom with same
beam parameters. After developing film is scanned with VIDAR vxr16 Dosimetrypro film scanner. Scanned film is then compared with dose plane output from XIO as shown in Figure- 2.

Figure-2: An example of a calculated dose profile exported from XiO (solid line-blue color) overlaid with a measured film profile (dotted line in red color).

**M. Record and verify systems**

Elekta synergy Linear accelerator record and verify system is interfaced directly with XIO. Primus Plus linear accelerator is interfaced threw Lantis network. Record and verify systems are provided by the linac manufacturers. Mapping between various accessories on the linac and the TPS are done, so that the devices such as the jaws and wedges are orientated correctly with respect to the patient’s anatomy. Communication between the TPS and the linac are checked , such as , the errors associated with manual transcription of paper printouts to the linac and can help in the treatment of complex cases involving asymmetric jaws and MLC shaped fields.
6.3. Results:

A: The Maximum % of variation between the TPS and the measured value is less than 2% for the both cases (brain and prostate).

B: Geometrical verification, the digitizer and plotter (printer) verification are done and all the obtained values are within the tolerance limits.

C: Asymmetric Jaws verification is done with the help of the film. The maximum deviation of the field sizes and field dimensions are less than 1mm. The position of the Jaw in film almost matching with TPS value (<1mm).

D: Dose Calculation: The maximum % of variation is less than 1% in case of comparing rotational photon and electron output.

E. Compatibility between the CT scanner and the TPS: For Catphan Phantom 503 an error in magnification is within the limits. All other values like contrast, resolution are with in the limits.

F. Output calibration: The maximum of difference is 0.005 cGy.

G. XiO MU calculations: The maximum % of variation is less than 1.5%.

H. Quality assurance of digitally reconstructed radiographs
All evaluated BEVs and DRRs agree with manual calculations to within ±1 mm. The DRRs also agree with the BEVs to within ±1 mm. This aspect of the treatment planning system is therefore found to be acceptable.

I, J and K: (Relative dose QA, Absolute dose QA and non-dosimetric QA):

In all the cases the Maximum % of variation between measured and TPS values are less than 2%.

The dose measured at isocenter point in the phantom is always within 2 % of the dose calculated by CMSXIO Planning system (Figure 11a). The results are shown here for various kinds of diagnosis. Maximum % of dose difference is found in ca. lung cases.

L. Dose profiles: Comparison of dose profiles is done. The maximum variation found is 2% at one particular point.

M. Record and Verify system: MU per beam, collimator rotation, table rotation, gantry rotation direction is checked. All these values are verified and found to be correct.

6.4 Conclusions: This paper describes the commissioning of the CMSXIO planning system for conventional, IMRT and IGRT techniques. Procedures and data needed to commission the planning system for intensity-modulated radiotherapy using multiple static fields are explained in detail. The dosimetric accuracy of the computed dose distributions relative to measurements in realistic phantoms taken into account. Various measurements are done to verify the system performance which is having various algorithms for calculation purpose.
6.5 References:

1. OSI oncology services international; CMSXIO IMRT: IMRT Planning,


