PhD Thesis Title: "A study on body phantom for improvement in dosimetry in modern radiotherapy techniques"

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Graduation Date: December 23, 2015
Available online: n/a

ABSTRACT

Purpose: A study on body phantom for improvement in dosimetry in modern radiotherapy techniques.

Background: Radiation Physics is playing an important role in medicine since the discovery of x-rays (1895), and radium (1898). The treatment of cancer using radiation is being done since 1896 just after discovery of x-rays, and the technological developments are still evolving. In current scenario the use of state of art technologies have made possible to deliver tumoricidal dose to target with minimal dose to the normal organs. *In vitro* dosimetric verification prior to patient treatment has a key role in accurate and precise radiotherapy treatment delivery. Modern radiotherapy practices, i.e. three-dimensional conformal radiation therapy (3DCRT), intensity-modulated radiation therapy (IMRT), image guided radiation therapy (IGRT), and rapid arc therapy use complex set of filed portal and apertures and planned dose verification before treatment delivery becomes increasingly important. Most of the commercially available dosimetry phantoms have almost homogenous density throughout their volumes. While the real interior of the patient body has variable and varying densities i.e. soft tissue, bones, and air cavities which are different from each other. This study has been done to develop and verify the physical Dosimetry in an actual human body scenario. Also, the effect of beam angles on planning dosimetric parameters has been studied. Before delivering the treatment plan, the patient position verification has a crucial role in the results of radiotherapy, similarly the phantom setup accuracy is a main important part of dosimetry; small shift in phantom position may lead to false dose measurements compared to planned doses on TPS. This study has also covered the selection of suitable imaging technology.

Materials and Methods: The 3DCRT and IMRT plans were generated on computed tomography (CT) images of patients with standard procedures by using 2 – 5 fields in 3DRT, and 5 – 9 fields in IMRT. Photon energies of 6 mega voltage (MV) and / or 15 MV in 3DCRT and 6 MV in IMRT were used. Dose was calculated using the anisotropic analytic algorithm (AAA). New technique of IMRT was developed for the pelvis, head-and-neck (H&N) and brain cases having large secondary nodes. Three pelvis (carcinoma (Ca.) of prostate with pelvic bony mets), three H&N (two cases of Ca. parotid with large secondary nodes and one case of Ca. base of the tongue with large secondary nodes), and three brain (glioblastoma multiform) IMRT patients were selected for the study. All the plans were created with a set of 6 – 9 beams having one or more pairs of parallel opposed beams. In both the techniques i.e. standard procedures and the new developed techniquewere applied. Each plan was analyzed based on planning target volume (PTV) coverage with 93%, 95%, 100%, 107%, and 110% of the prescribed dose (PD), organs at risk (OARs) doses, homogeneity index (HI), conformity index (CI), and normal tissue integral dose (NTID).

The quality assurance (QA) plans were made by exporting the above plans (plans done by standard procedures) on CT images of different homogeneous (slab phantom, acrylic head phantom), and heterogeneous phantoms (goat head as "head phantom" and goat meat with bones and air cavities as "tissue phantom"). After approving all the QA plans and scheduling for delivery, all the phantoms were set on clinical electron linear accelerator (Clinac) couch. The QA procedure from CT scan to plan delivery using each phantom was done on separate days to avoid any error, and have adequate time for proper and standard QA procedure. On-Board-Imaging (OBI) system was utilized for phantom setup verification, kilo voltage - orthogonal portal imaging (kV – OPI) was done in case of homogeneous phantoms (slab and acrylic head phantoms), and the setup accuracy was checked by matching ion chamber to ion chamber position by superimposing the OPI and digital reconstructed radiographs (DRRs). kV – Cone beam CT (kV – CBCT) was performed in case of heterogeneous phantoms (goat head and tissue phantoms), and the position of ion chamber, bones and tissues were verified by superimposing the CBCT images on reference CT images. A separate study was done for choosing either OPI or CBCT for setup verification. The minor shifts observed during phantom setup verification were applied and all the plans were delivered. Dose for each plan was measured following the Task Group Report No. 398 (TRS – 398) of the International Atomic Energy Agency (IAEA). The measured and planned doses were compared and analysed.

Results: In all the plans done by standard procedures and the new developed techniques, the doses to OARs were well within tolerance limits and the PTV coverage for 93%, 95%, and 100% of PD was very well obtained (followed the radiation therapy oncology group criteria "95% and 99% volume of PTV should receive 95% and 93% of the PD, respectively"), and values of HI, CI, and NTID were also satisfactory. In summary, very good OAR sparing and PTV coverage were observed in all the plans. In the study of OPI *vs.* CBCT techniques there was statistically no significant difference between both the imaging techniques for the brain, head-and-neck (H&N) and pelvic cases.

In the first phase of patient specific dosimetry, the mean percentage variation between planned and measured doses was found to be 2.48 (standard deviation (SD): 0.74), 2.36 (SD: 0.77), 3.62 (SD: 1.05), and 3.31 (SD: 0.78) for 3DCRT (goat head phantom), IMRT (goat head phantom), 3DCRT (goat tissue phantom) and IMRT (goat tissue phantom), respectively. In the second phase of this study, the mean percentage variation between planned and measured doses of all IMRT QA plans was found to be 0.65 (SD: 0.38) with confidence limit (CL) 1.39, 1.16 (SD: 0.61) with CL 2.36 and 2.40 (SD: 0.86) with CL 4.09 for slab phantom, acrylic head phantom and goat head phantom respectively.

Conclusion: From all the main and associated experiments done under this study, the following conclusion can be made out;

- The use of one or more pairs of parallel opposed beams in IMRT plans in some special pelvis, H&N and brain cases having large secondary nodes offers the benefit in terms of critical target volume irradiation, while maintaining the OARs within tolerable limits.

- kV – CBCT is not a mandatory technique compared to the kV – OPI technique in routine brain, H&N, and pelvic cases, except in those cases where better information about interfraction movements of soft tissue is necessarily required for positioning of the target, as is the case in Ca. prostate.

- It is logical and rational to develop radiation dosimetry methods based on real human body and to develop an artificial phantom which should truly represent the interior of human body.

- The algorithm AAA does not calculate doses in heterogeneous medium as accurate as it calculates in homogeneous medium. Therefore the patient specific absolute dosimetry should be done using heterogeneous phantom mimicking density wise as well as design wise to the actual human body.

References to author publications that relate specifically to the dissertation:

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