ABSTRACT

Radiation therapy machines have evolved from very low energy x-ray machines into a variety of treatment options that include high-energy electrons, photons, and heavier particles such as neutrons and protons. The goal of radiation therapy is to kill tumor cells while at the same time limiting the dose to normal tissues. Accomplishing this goal will enhance tumor control probability and limit the adverse side effects that result from irradiating healthy tissue. Radiation is conformed to the tumor volume by several means viz, collimators and custom blocks. To further minimize the amount of radiation passing through healthy tissue during the irradiation of the target, several beams may be utilized from different directions to deliver the total dose, rather than a single beam. In this way, doses from the different beams add together to maximize the dose to the tumor volume and minimize the unnecessary radiation to the healthy tissues well below their tolerance limits. These beams may be assigned different weights to further limit the amount of radiation passing through sensitive structures.

To overcome the limitations in conventional radiation therapy, much advancement in Radiation therapy have come. Among these, recently Intensity Modulated Radiotherapy (IMRT) has been considered as an alternative radiation therapy (RT) modality in improving the therapeutic efficacy over conventional RT. IMRT is basically modulation of the radiation beam intensity in three-dimension throughout the treatment field. IMRT
provides a better fit to the tumor volume than the conformal radiation therapy. The treatment plans for IMRT are generated with an inverse planning technique. In inverse planning, the physician can prescribe not only the dose to be delivered to the tumor volume but also limit the dose to the healthy structures surrounding the tumor volume. In IMRT, either compensators or Multileaf Collimators (MLC) are used to modulate the intensity of each beam. This may be carried out by two different methods such as dynamic MLC (sliding window) and step and shoot delivery. In dynamic MLC, the leaves are in constant motion throughout the beam delivery and in step and shoot delivery, the beam delivery is paused while the leaves are repositioned. Even though IMRT gives a newer look to the radiotherapy, there are many associated risks and difficulties, if IMRT is not properly delivered. For example, accurate beam data collection with proper instruments and commissioning the beam with MLC, selection of beam energy and reproducibility of the patient setup may influence the treatment end result. In this regard, the scientific community is trying to deliver the required radiation to various tumor volumes with different margins in the order of millimeters and protect the normal tissues, in particular the critical organs. This is achieved by developing more powerful algorithms.

In this context, to overcome the inaccuracies due to above said reasons, the IMRT systems are equipped with on board handy imaging systems viz. ultrasound or/and mega voltage (MV) imaging, kilo voltage (KV) imaging, and cone beam CT (CBCT) techniques. This powering of IMRT with image guidance is referred as IGRT. The different imaging
devices in IGRT gather information about the patient setup prior to treatment delivery. If the patient is misplaced on the couch, then suitable corrections are made such that the patient can be treated as was decided during treatment-planning.

A computerized treatment planning system (TPS) is an essential tool to design and evaluate the accurate radiation dosimetry in the radiation therapy of both malignant and non-malignant diseases (IAEA TRS-430 2004, Fraass et al 1998, Van Dyk et al 1993). Hence it needs to be commissioned with all the add-on materials including MLC. However, commissioning of a MLC in TPS for intensity modulated radiation therapy (IMRT) requires beam data such as percentage depth dose (PDD), beam profiles, output factors and MLC transmission characteristics of the linear accelerator concerned. Based on the instruction given by the planning systems manufactures beam data must be collected with great accuracy using suitable detectors. This is highly essential, because Stereotactic Radiosurgery (SRS) and Stereotactic radiotherapy (SRT) deliver higher dose in shorter period of time, hence at most care should be taken to avoid the radiation dose misadministration. Although, most of the commercial TPS require the beam data measured with routine collimator jaws, some TPS deals with narrow beam. Corvus inverse planning system from Best NOMOS and Brainscan from BrainLAB require the data from MLC shaped fields.

Further, the total scatter factor (SF) (or relative output factor), percentage depth doses (PDD), cross / inline beam profiles and profiles in air are the basic dosimetry parameters for a photon beam commissioning. An
accurate and precise measurement of these dosimetry parameters has been a long-time challenging task in medical physics because there are many sources of errors associated with them. For example, the lateral electron disequilibrium, the detector volume effect, collimation effect (Paskalev et al 2003), and detector position-orientation effect are the common ones. Conventional measurement for the small fields requires very precise fixation of the detector at the center of the small field at the depth of interest in the water or water-equivalent phantom. The center is usually located at the peaks of the scanned dose profiles across the small, square or circular field. A sub millimeter displacement of the measuring point from the central point (0.2 to 0.5 mm) due to electronic and mechanical uncertainties of the scanning system may yield a significant difference (>10%) among the measured peak values.

Stereotactic-type silicon diode, MOSFET, diamond detector, ion chamber, and thermoluminescence dosimeters have often been used for the small field measurements (Laub et al 2003). Various film dosimeters have also been used for relative output check and dose profile acquisition (Ma et al 2000). A stereotactic-type dosimeter should have the spatial resolution much smaller than the size of the fields to be measured. If the dimension of the sensitive volume of the detector is comparable to the size of the field, an extended distance technique could be applied for the dose measurement and the increment of the phantom scattering and the decrement of the collimator scattering should be corrected (Khan 1994). Even with those stereotactic detectors, careful detector-phantom setups, and detailed dose corrections, one
might still find more than 10% discrepancies among the measurements of very small fields (<10 mm in diameter) (Cheung et al 1999). After the selection of beam definer and detector, the beam energy is an important factor in achieving the goal of radiotherapy using Image Guided Radiation Therapy.

In radiation therapy of deeper targets, high energy radiations of energies $\geq 10$ MV are preferred in particular, for deep-seated pelvic/abdominal lesions of larger target volumes or larger size patients (Laughlin et al 1986) due to the decrease in the integral dose. In addition, it has been shown that dose deposition is different for different energies near and away from the target. Low energy radiation produces higher dose distributions around the target than higher energies, however it deposits higher surface dose (Laughlin et al 1986, Garrison et al 1952).

In contrast, one of the studies on IMRT indicates that the energy does not matter or is less important (Sternick et al 1997). On the other hand, it has been suggested by Soderstrom et al (1999) that there is still a value to higher energies for deep seated targets as the volume of the target increases. In addition, the total monitor units are typically two to three times higher in IMRT than in conventional radiation therapy. Therefore, the use of high-energy photons also raised concerns about increased leakage and secondary neutron dose for the patients (Howell et al 2005, Kry et al 2005, Waller et al 2003). However, it is unclear whether low-energy intensity-modulated photons can be used for large-pelvis irradiations because of the low penetration power of the beam and its effectiveness in achieving the goal of radiotherapy.
Besides the above, the accuracy and maintenance of the reproducibility of the patient setup are other important requisites in radiotherapy because of the proximity of the treatment volume to critical structures such as the spinal cord, brainstem, and parotid glands. When intensity-modulated radiotherapy (IMRT) is used, proximity of this kind between the target and normal organs often leads to highly inhomogeneous dose gradients.

The On-Board Image system (Varian Medical Systems, Inc., Palo Alto, CA) for IGRT is one among the other imaging systems available to correct for organ motion and setup errors during radiation therapy. The OBI system provides three imaging modes: two-dimensional (2-D) radiographic acquisition, fluoroscopic image acquisition, and three-dimensional (3-D) cone-beam computed tomography (CBCT) acquisition. The use of this new technology necessitates a comprehensive quality assurance (QA) program to maintain and monitor system performance characteristics. Currently, there have been no published recommendations and guidelines for a QA program to verify the functionality, accuracy, stability, and image quality of the radiographic and CBCT modes of this device in Image Guided Radiation Therapy.

Based on the above said constraints and controversies among medical physicists, the present thesis is aims at the following objectives.
1. To investigate whether beam data with jaws differ than that with MLC and whether the jaw based beam data would suffice for the commissioning of a MLC on a TPS.

2. To compare two detectors with different measurement volumes for beam data measurements in the case of narrow photon beams.

3. To study the effect of beam energy on the quality of IMRT/IGRT plans for prostate radiotherapy for 6 and 10 MV photon beams.

4. To formalize the specific quality assurance tests for Varian On board imager for Image Guided Radiotherapy.

The present thesis is organized into seven chapters.

The first chapter discusses the principles of various clinical radiation dosimetry and presents an overview of different radiotherapy procedures. As the present thesis discusses about IMRT/IGRT applications, an introduction to IMRT, MLC, Treatment Planning system commissioning, small volume diode detectors are discussed in brief. The importance of reducing the setup error to the order of millimeter using on board imaging in Image guidance radiotherapy is also detailed. In addition to these, the effect of beam energy in prostate IMRT treatments is also discussed.

Chapter two describes Materials and Methods of the different work carried out in the present thesis work. It also discusses about the types of
treatment machines, and different types of the phantoms and the detectors used. The experimental set up and nature of the study of the different types of work performed are also given.

In Chapter three the comparison of beam data requirements for MLC commissioning on a TPS is emphasized. Beam data like percentage depth dose (PDD), cross beam profiles and output factors were acquired from three different Linear Accelerators using jaws and MLC (millennium 120 MLC) separately as a beam definer are also discussed. Further, the methods of determining percentage depth dose and beam profiles are discussed along with the details of RFA and various detectors used for measurement of the same.

Chapter four describes the effect of detector size on beam data measurements for narrow photon beams. In this study, m3-micro MLC (BrainLAB GmbH, Germany) and Clinac 600 C Linear Accelerator (Varian Medical Systems, Palo Alto, CA USA). Med-Tec TG-51 water tank and Standard Imaging Max 4000 electrometer were used for all the measurements. TG-51 protocol was followed to establish the absolute dosimetry using PTW 0.6cc chamber and Keithley – model no.35040 electrometer. Using CC13S (volume 0.13 cm³ and inner radius 3 mm) and SFD Diode detector (diameter of the active area 0.6 mm and thickness of active volume is 0.3 mm) with RFA 200 radiation field analyzer the required PDD, scatter factors, diagonal profiles, MLC leakage and transmission factors were also measured and compared and their results are discussed.
The dosimetric parameters like PDD, diagonal profile, scatter factor and dynamic leaf shift were measured with CC13S chamber and SRS diode detector in order to identify the most appropriate detector for the dosimetry of narrow photon beams defined by micro Multileaf Collimators. It is found that the surface dose values measured by the diode detector are higher and the PDD values are lower than that measured with CC13S chamber for field size smaller than 8 x 8 cm².

Chapter five describes the influence of photon beam energy on IMRT plan quality of prostate cancer. In this study 20 prostate cases were selected. All patients were given full-course of IMRT to a total dose of 79.2 Gy in 44 fractions. For inverse IMRT treatment planning, we used 6-coplanar non-opposed beam arrangements at 225, 270, 0, 75, 105 and 135 degree angles for both 6 MV and 10 MV photons. It is noted that the treatment plans for both 6 MV and 10 MV intensity modulated beams were developed under identical dose volume constraints. The developed dose volume histograms (DVHs) for 6 MV and 10 MV photons were compared for PTV and for critical structures such as the rectum, bladder, femoral heads, small intestine and urethra. The conformal index was also computed and compared. The integral dose to the normal surrounding tissue by integrating the dose over all voxels within the patient volume was also calculated. Since it is found that, there is no greater advantage from 10 MV photons as compared with 6 MV photons in large volume pelvic IMRT dosimetry, it is suggested that the use of 6 MV photons for IMRT of prostate cancer gives better results in tumor
control and acceptable probability of complication rate. The details of results are given in this chapter.

In the sixth chapter the necessity of Quality assurance of Varian on-board imager which is the most important tool in achieving the goal of radiotherapy is emphasized. A series of QA tests were performed with equipments and tools as recommended by Varian and as per their QA protocols OBI customer acceptance procedure and OBI CBCT customer acceptance procedure. In this chapter the modality of QA is also suggested.

The final chapter deals with the conclusions and possible directions of the future work.