CHAPTER 2

INSTRUMENTATION

This chapter deals with the specific equipment and devices that were used to achieve the defined research objectives. These equipment and devices include a linear accelerator, a radiation field analyzer, various radiation detectors, phantoms, treatment planning system, and pretreatment verification devices. The detailed explanation about these instruments has been given below.

2.1 LINEAR ACCELERATOR

The True beam LINAC (Varian Medical Systems, Inc., Palo Alto, CA, USA) used in this study can generate both FF and FFF photon beams (Figure 2.1). It has FF photon beam energies of 6, 10, and 15 MV, as well as FFF photon beam energies of 6 and 10 MV, and nominal electron energies of 6, 9, 12, 15, and 18 MeV. It is equipped with millennium 120 MLC with a pair of 60 opposed leaves. These leaves are mounted in two leaf banks beneath the ‘X’ jaws. Each of the central 80 leaves has a leaf width of 0.5 cm at the isocenter, while the rest have a leaf width of 1.0 cm. The MLC-120 has a full 40 × 40 cm2 field size at a source to axis distance (SAD) of 100 cm. The MLC speed ranges from 0.0 to 2.5 cm/sec.

The minimum static leaf gap and dynamic leaf gap between opposite banks were 0.0 mm and 0.5 mm, respectively. The leaves interdigitate, and the upper and lower jaws travel ranges were -20 mm to +200 mm and -100 mm to +200 mm, respectively. The gantry speed ranges from 0.0 to 1.0 RPM (Rotation Per Minute), with a rotational accuracy of less than 0.3 degree. The maximum nominal dose rates for conventional FF photon beams ranged from 0 to 600 MU/min, while FFF photon beams ranged from 0 to 2400 MU/min. The machine's output was calibrated to 1 cGy/MU at dmax for reference field size at 100 cm source to surface distance (SSD) using the TRS-398 protocol.

Figure 2.1: TrueBeam Linear Accelerator

2.1 3D SCANNER RADIATION FIELD ANALYSER (RFA)

The 3D SCANNER is a fully automated 3D dosimetry cylindrical water tank (Figure 2.2). This feature, together with the elimination of tank shifts, eliminates scanning subjectivity, saves time, and ensures that measurements are reproducible regardless of user. It has a diameter drive that ensures consistent detector orientation for in-plane, cross-plane, diagonal, and all other angles across the entire 360º circumference. The 330º rotation range eliminates the need for tank shifts. By combining rotation and diameter movements during the measurement, the 3D SCANNER system supports off-axis scans with this geometry. 360º scanning with consistent detector orientation yields better data and eliminates the need to change tank setup.

Using two electric motors, the 3D SCANNER water sensor measures the water surface relative to the scanning mechanism at three points and automatically adjusts the water tank levelling. Physically levelling the water tank allows for quick and easy visual QA of the process as well as more accurate scanning. 3D SCANNER measures a 10 x 15 cm beam to determine the centre of the beam in relation to the centre of 3D SCANNER. The centre of the 3D SCANNER is then aligned with the centre of the beam using two electric motors. 3D SCANNER uses a series of beam measurements to determine in-plane and cross-plane home positions automatically. SNC Dosimetry scanning software is used in the 3D SCANNER. SNC Dosimetry is a modern software application that provides both familiar concepts from existing water tank conventions and new tools not previously available with a 3D water tank system.

Figure 2.2: Sun nuclear three dimensional (3D) scanner water phantom

2.2 DOSIMETRIC DETECTORS

2.2.1 SNC125c Ionization chamber

SNC125c is a waterproof and fully-guarded thimble ionisation chamber (Figure 2.3) with a design that minimises convolution of high-dose gradient regions during profile and depth measurements. It is designed for scanning, field, and reference dosimetry measurements.

Figure 2.3: SNC125c ionization chamber

2.2.2 PinPoint ionization chamber

PinPoint ionization chamber is ideal for measuring dose in small fields, such as those encountered in IMRT and stereotactic beams (Figure 2.4), as well as for FFF. When the chamber is moved perpendicular to the chamber axis, relative dose distributions can be measured with very high spatial resolution. The fully guarded, waterproof chamber can be used in air, solid state phantoms, and water phantom.

Figure 2.4: PinPoint ionization chamber

2.2.3 EDGE detector

The EDGE Detector is a waterproof dosimeter with a unique design that virtually eliminates convolution of high dose gradient regions during profile and depth measurements (Figure 2.5). It is designed to measure fields as small as 5 mm and as large as 10 x 10 cm.

Figure 2.5: Edge detector

2.2.4 Thermoluminescence dosimeter (TLD)-100 chips

TLD-100 materials based on lithium fluoride are tissue-equivalent and provide excellent energy response (Figure 2.6), eliminating the need for extensive mathematical computations to determine dose, improving overall accuracy, and reducing the possibility of costly errors. Furthermore, Lithium Fluoride-based materials are not light sensitive, allowing for greater flexibility in dosimeter handling and processing, resulting in increased productivity and process efficiency.

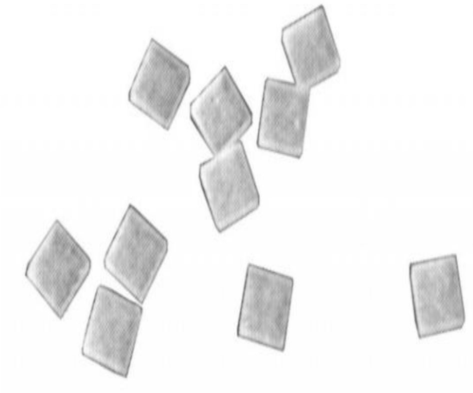

Figure 2.6: Thermoluminescence dosimeter (TLD)-100 chips

2.2.5 GafChromic film

Radiochromic film, also known as GafChromic, used radiation-induced polymerization to produce darkening proportional to absorbed dose (Figure 2.7). Through a polymerization reaction, radiochromic film self-develops. Radiochromic film has largely replaced radiographic film (which requires chemical development) for dosimetry purposes due to its self-development feature.

Figure 2.7: GafChromic film

2.3 TREATMENT PLANNING DEVICES

2.3.1 Rando Phantom

The Alderson Radiation Therapy (ART) phantoms are essential QA tools (Figure 2.8). They offer comprehensive tests of the entire treatment planning and delivery chain. Tissue-equivalent material is used to make ART Phantoms. They are designed to meet International Commission on Radiation Units and Measurements (ICRU)-44 standards while adhering to highly sophisticated technological constraints for accuracy and ease of use. The RANDO man phantom, an anthropomorphic phantom made of tissue-equivalent material embedded in a natural human skeleton with no arms or legs, was used in this study. The muscle and soft tissue were simulated with polyurethane. To simulate the lungs, a material with the same effective atomic number as the soft tissue material but a density nearly three times lower was used. The phantom is a male body with a height of 175 cm and a weight of 73.5 kg. The RANDO man phantom was sliced at 2.5 cm intervals. Treatment planning was based on computed tomography (CT) images of the RANDO man phantom with a slice thickness of 1.5 mm.

Figure 2.8: Rando Man Phantom

2.3.2 Eclipse Treatment Planning System (TPS)

The Eclipse TPS (Varian Medical Systems, Palo Alto, CA) is a comprehensive solution designed to simplify modern radiation therapy planning for all types of treatments, such as 3DCRT, IMRT, IGRT, VMAT, electron, proton, and brachytherapy. Eclipse's 3D conformal planning tools are combined with interactive dose-volume optimization to provide IMRT planning that is said to be fast, flexible, and accurate. The task of selecting the best beam angles for fixed-beam IMRT is simplified by automatic optimization of beam geometry.

Eclipse also includes an automatic contouring feature called Smart Segmentation, which is the first fully automatic tool that uses intelligent software to identify and outline organs and other structures that will be irradiated or protected during treatment within diagnostic images. Eclipse is tightly integrated with Varian's ARIA Oncology Information System, so treatment plans from Eclipse are immediately accessible as part of the patient's electronic medical record on ARIA workstations throughout the department, with no need for data import or export.

2.4 PRETREATMENT VERIFICATION DEVICES

2.4.1 ArcCHECK

AAPM Task Group 218 recommends ArcCHECK for 3D measurement requirements for patient specific QA (Figure 2.9). ArcCHECK provides accurate plan delivery data as well as insights into potential errors. It is made up of a helical detector grid with 1,386 SunPoint diode detectors to increase the data density of the beam's Eye View (BEV). Using the Virtual Inclinometer, it can provide angular corrections accurate to 0.5°. It can produce consistent BEV for all gantry angles, measuring entrance and exit dose at multiple depths and indicating potential delivery and TPS modelling errors for high and low dose levels. It includes a real-time electrometer that measures each pulse as well as composite and sub-arcs. It comes with SNC patient software that compares the dose distribution in the treatment plan file to the actual measured values. Distance-to-agreement (DTA) or gamma analysis is used in this software to compare relative or absolute dose data.

Figure 2.9: ArcCHECK diode array

2.4.2 MapCHECK 3

MapCHECK 3 is a two-dimensional diode array with the highest detector density, smallest detector size, and largest field size for IMRT QA (Figure 2.10). It is made up of 1,527 SunPoint 2 diode detectors that each measure 0.48 mm and cover a field of 32 x 26 cm. The SNC Patients software allows for the quick analysis of QA measurements against the plan. Assuring physician prescriptions and intended doses are delivered to the patient accurately and consistently. It has a real-time electrometer that measures each pulse every 50 milliseconds. It comes with SNC patient software, which compares the measured dose to the planned dose with a single click. DTA or gamma analysis is used to compare relative or absolute dose points.

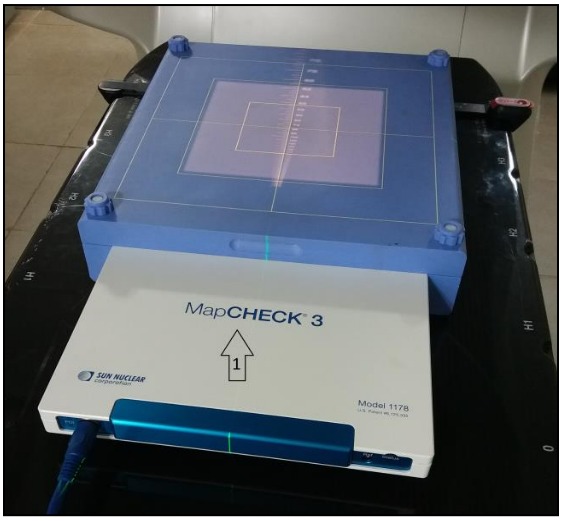

Figure 2.10: MapCHECK 3 diode array

2.4.3 Portal dosimetry system

Portal Dosimetry is a QA application used to verify the pre-treatment IMRT and VMAT plans. During a treatment session, it employs an electronic portal imaging device (EPID) to measure the intensity of X-rays transmitted through a patient from a radiation port (Figure 2.11). The entire portal dosimetry process requires three components: Eclipse portal dose calculation (PDC) to create a prediction of the expected portal dose image, EPID to measure the portal dose image, and portal dosimetry application to compare the measured and predicted images. The system has several advantages, including no phantom requirement, quick image acquisition and digital output, and high resolution.

Figure 2.11: Electronic portal imaging device based portal dosimetry system

2.4.4 PerFRACTION

PerFRACTION (Sun Nuclear, Melbourne, FL, USA) is 3D in vivo dosimetry software that provides near real-time and online verifications of the radiation dose delivered during clinical treatment. This software makes use of monitor chamber dose rate and output data, as well as the patient's exit fluence as recorded by the EPID during treatment. It reconstructs the 3D dose distribution in the pretreatment planning CT or in an acquired cone-beam CT (CBCT). PerFRACTION can do both pretreatment verification QA (called "Fraction 0") and in-vivo transit dosimetry (called "Fraction n") using point and 2D analysis with EPID images and 3D analysis with log files and cone beam CT (photon beams only, not electrons).