BASICS OF COMPUTED TOMOGRAPHY SIMULATION

PROJECT REPORT
IN FULFILLMENT OF THE REQUIREMENT FOR THE
AWARD OF THE STUDY WORK DONE UNDER
Mr.RANGARAJ BHATTACHARJEE (PHYSICIST).

BY
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CERTIFICATE

This is to certify that this project Entitled "BASICS OF COMPUTED TOMOGRAPHY SIMULATION" embodies the result of dedicated study work carried out at this institute by Shri PURNENDU DEB ROY, CT Technician/Radiographer, Diagnostic Unit, Cachar Cancer Hospital & Research Centre, Silchar, Assam, under the supervision & guidance of Mr. Rangaraj Bhattacharjee (Physicist) during the period 1st January'2011-5th February'2011.

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CERTIFICATE

This is to certify that this project report "BASICS OF COMPUTED TOMOGRAPHY SIMULATION" being submitted by Shri PURNENDU DEB ROY, CT Technician/Radiographer, Diagnostic Unit, Cachar Cancer Hospital & Research Centre, Silchar, Assam, is a bonafide record of the study work carried out by him under my supervision & guidance during the period 1st January'2011-5th-February'2011 and his study work has not been submitted elsewhere for a degree.

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Mr.Rangaraj Bhattacharjee
(Medical Physicist cum R.S.O.)

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CHAPTER-1

INTRODUCTION:

Before X-rays were discovered by Sir Wilhelm Conrad Roentgen, the first role of a physician was to diagnose what was wrong with the patient before considering the prognosis and providing treatment. Accurate diagnosis was most dependent on the history obtained and the physician's skill at questioning the patients. But at the same time the physician used the senses, sight, touch, hearing, smell and even taste to identify abnormalities in the patient. Hippocrates had developed observation of the patient and the progress of their disease as the science of medicine. He described the appearance of the patient, felt their temperature, and smelled their vomit. Although doctors became particularly skilled at examining the lumps, cuts and breaks of the body (i.e., "external" medicine), they rarely tried to examine the inside of the body. There were exceptions such as when Hippocrates shook the patient with pleurisy to detect a splash when there was fluid in the pleural space; thus the Hippocratic Succussion Splash. Observations are considered to be more scientific if measurement of them can be made. In Alexandria, Herophilus 300 BCE would feel the pulse and count it using a water clock. Galen, 129 ACE, relied heavily on touch or palpation for diagnosis and essential skill for assessing wounds and injuries. Galen had practiced sports medicine with the gladiators. He would describe the general appearance of the patient but also tasted sweat for jaundice and listen to the rumbling abdomen. Galen learned much from feeling the pulse, which he did in both wrists using three fingers. The pulse was thought to reveal disorders of the organs of the body. There is much in common with what was understood by him from the pulse and Chinese medicine - perhaps a spread of ideas along the Silk Road. The Chinese did not measure the pulse but were said to learn many things from its feel. In 1583 a medical student was bored by a sermon and observed that the swinging of the altar lamp was unvarying and that this could be used to measure time. The student was Galileo (1564-1642) who, as we know, gave up medicine for astronomy fame and ill fortune at the hands of the Catholic Church. Galileo's pendulum clock was adapted by Sanctorius (1561-1636) to measure the pulse. Sanctorius was considered to be a major physiologist because he used a thermometer to measure temperature, and a weighing chair to measure the intake and output of food and fluid. But since there was little understanding of the function of the body, these measurements did not advance medicine. This was to change with the Italian Renaissance and the lessons of the anatomists who identified the true state of the organs of the body and set the scene for understanding their function. The work of the Englishman William Harvey (1575-1657) who had studied in Italy described the circulation of the blood but added nothing to the diagnosis of disease. He thought the heart distributed the humours and spirits. In 1707 Sir John Floyer (1649-1743) introduced the pulse watch and thought it of more value than Harvey's work. Physicians began to count the pulse regularly and would note it in various ways. In 1731 a new dimension was added to the measurement of the body with the work of Stephen Hales (1677-1771) who studied the pressure in arteries and veins. He would insert a cannula into the vessels and measure the height of the column of blood – that is he measured the blood pressure.

But these advances were relatively meaningless until the understanding that diseases were often abnormalities of the structure or function of organs. After Dr. Roentgen's discovery, medicine inalterably changed (of course, X-ray discovery was not the only impetus for medical change, others included anesthesia, the notion of sepsis, etc).

One fine Friday evening, 8 November 1895, Wilhelm Conrad Roentgen discovered a "new kind of ray" that penetrated matter. Roentgen, a 50-year old professor of physics at Julius Maximilian University of Wurzburg, named the new kind of ray X-strahlen "X-rays" ("X" for unknown). Roentgen was looking for the "invisible high-frequency rays" that Hermann Ludwig Ferdinand von Helmholtz had predicted from the Maxwell theory of electromagnetic radiation. Roentgen's discovery was submitted for publication on 28 December 1895 and was published on 5 January 1896. Roentgen developed the first X-ray pictures on photographic plates, and one of the first materials tested was human tissue. The most famous picture was an image of his wife's hand with a ring on her finger. In 1901 Roentgen received the Nobel Prize for Physics, which was the first Nobel Prize in physics ever awarded. The first medical use of the X-ray was on 13 January 1896 by Drs. Ratcliffe and Hall-Edwards, in which they showed the location of a small needle in a woman's hand. As a consequence, Dr. J.H. Clayton performed the first X-ray guided surgery nine days after the publication of the existence of X-rays. Also in 1896 Randolph Hearst (of the famous Hearst publishing dynasty) offered a challenge to scientists to capture an image of the brain. Many tried, and all failed, even though some novel imaging enhancement techniques were invented. For example, air was injected into the fluid-carrying compartments of the brain (pneumoencephalography). The test subjects reported no major physical discomfort (the brain has no pain receptors), though they developed unusual behavior, mentation, cognition, and motion patterns. Allan Macleod Cormack (Tufts University) and Godfrey New bold Hounsfield (research labs of EMI, Ltd.) developed the necessary mathematics (1962) and the first hardware implementation of the CT scanner (1972) that was able to image the brain. This scanner was able to compute one CT image in about 24 hours. Cormack and Hounsfield shared the Nobel Prize in Physiology and Medicine in 1979. Note: Hounsfield never claimed that he invented CT. The original concept was published in 1917 by an Austrian mathematician, J. Radon, working with gravitational theory that a two or three dimensional object could be reproduced from an infinite set of all its projections. Thus, the mathematical concept was established 55 years before the production of a commercial CT scanner. In 1956, Bracewell, working in radio astronomy, constructed a solar map from ray projection. Oldendorf (1961) rotated a head phantom on a gramophone turntable and provided simultaneous translation by having an HO-gauge railway track on the turntable. This contraption was pulled slowly through a beam of X-rays falling on a detector. Oldendorf showed the internal structure of the phantom. Kuhl & Edwards in 1968 built a successful mechanical scanner for nuclear imaging, but did not extend their work into diagnostic radiology. Even earlier, there were reports (1957, 1958) from Russia (actually CCCP at that time) that a working CT machine was built.

PHYSICS OF X-RAY PRODUCTION:

There are two different mechanisms by which x-rays are produced. One gives rise to bremsstrahlung x-rays and the other characteristic x-rays.

A. Bremsstrahlung:

The process of bremsstrahlung (braking radiation) is the result of radiative (interaction) between a high-speed electron and a nucleus. The electron while passing near a nucleus may be deflected from its path by the action of Coulomb forces of attraction and lose energy as bremsstrahlung, a phenomenon predicted by Maxwell's general theory of electromagnetic radiation. According to this theory, energy is propagated through space by electromagnetic fields. As the electron, with its associated electromagnetic field, passes in the vicinity of a nucleus, it suffers a sudden deflection and acceleration. As a result, a part or all of its energy is dissociated from it and propagates in space as electromagnetic radiation. Since an electron may have one or more bremsstrahlung interactions in the material and an interaction may result in partial or complete loss of electron energy, the resulting bremsstrahlung photon may have any energy up to the initial energy of the electron.

B. Characteristic X-rays:

Electrons incident on the target also produce characteristic x-rays. An electron, with kinetic energy E_0, may interact with the atoms of the target by ejecting an orbital electron, such as a K, L, or M electron, leaving the atom ionized. The original electron will recede from the collision with energy ($E_0 – E$), where “E” is the energy given to the orbital electron. A part of “E” is spent in overcoming the binding energy of the electron and the rest is carried by the ejected electron. When a vacancy is created in an orbit, an outer orbital electron will fall down to fill that vacancy. In so doing, the energy is radiated in the form of electromagnetic radiation. This is called characteristic radiation, i.e., characteristic of the atoms in the target and of the shells between which the transitions took place. With higher atomic number targets and the transitions involving inner shells such as K, L, M, and N, the characteristic radiations emitted are of high enough energies to be considered in the x-ray part of the electromagnetic spectrum.

CHAPTER-2

RADIOTHERAPY OR RADIATION THERAPY:

Radiotherapy is the use of ‘radiation’ to destroy cancer cells. During this radiation process the normal cells surrounding the tumor can also be affected, which can lead to side effects. Approximately four out of ten people with cancer (40%) have radiotherapy as part of their treatment. Radiotherapy is generally used as; a curative or radical treatment to destroy the tumor; a palliative treatment to relieve symptoms; neoadjuvant or induction treatment to shrink the tumor or reduce the risk of it spreading during surgery or as an adjuvant treatment to kill off any tiny amounts of tumor that may have been left after surgery. The radiation dosage given to patients depends on the location of the tumor, the size and type of the tumor and the patient’s general health. The total dose required is divided into smaller doses called 'fractions', which are administered over a number of days or weeks.

The Radiation therapy is basically of three types namely-

1. **Teletherapy-** radiation treatment given from a distance, using radioisotopes or beams of charged particles.
2. **Brachytherapy-** treatment with a radioisotope at a short distance i.e., in contact or very close to the tumour or from within the tumour.
3. **Internal radiotherapy-** a part of nuclear medicine where the treatment uses a radioisotope to be taken orally or intravenously.

TELETHERAPY UNIT OF OUR HOSPITAL:

In our hospital we have a **Theratron 780E unit**, maker Theratronics Pvt. Ltd. Canada. The unit has been installed in **22nd of October 2005** & the source was loaded on **6th of January 2006**. The Radioisotope we are using is **Cobalt-60** having two energies 1.33MeV & 1.17MeV. The average energy **1.25MeV** is used for the treatment purpose. The half-life of Cobalt-60 is **5.26 years**. We have a treatment planning system **CMS XiO-3D TPS** Kirloskar, Theratronics Pvt. Ltd., installed on **7th of January 2006**; it is based on electron density.

Staffing:

The quality of treatment largely depends on the strength of the radiotherapy team. Besides the physician specialists, the radiation oncologists, radiotherapy requires the services of medical physicists, dosimetrists, technologists, and nurses.

The radiation oncologist, who has the ultimate responsibility for the care of the patient, heads the treatment planning team. The final plan must meet the approval of the radiation oncologist in charge of the patient. One of the roles of the medical physicist in radiotherapy is specifically in treatment planning; the physicist has the overall responsibility of ensuring that the treatment plan is accurate and scientifically valid. That means that the physicist is responsible for testing the computer software and commissioning it for clinical use. He or she is also responsible for proper interpretation of the treatment plan as it relates to the dose distribution and calculation of treatment duration or monitor units. One important role of a medical physicist that is often overlooked is that of a consultant to radiation oncologists in the design of the treatment plan. The unit team of radiation oncologist and medical physicist must have a supporting cast to provide radiotherapy service effectively to all patients referred to the department.

Various steps in External Beam Therapy:

1. Diagnosis of the disease.
2. Treatment planning is a process that involves the determination of treatment parameters considered optimal in the management of a patient's disease. In radiotherapy, these parameters include:
    a. Target volume assessment.
    b. Dose-limiting structures.
    c. Treatment volume.
    d. Dose prescription.
    e. Dose fractionation.
    f. Dose distribution.
    g. Positioning of the patient.
    h. Treatment machine settings.
    i. Adjuvant therapies.
3. The final part of these activities is a blueprint for the treatment, to be followed meticulously and precisely over several weeks.

Treatment planning starts right after the therapy decision is made and radiotherapy is chosen as the treatment modality. The first step is to determine the tumor location and its extent. The target volume, as it is called, consists of a volume that includes the tumor (demonstrated through imaging or other means) and its occult spread to the surrounding tissues or lymphatics. The determination of this volume and its precise location are of paramount importance. Considering that radiotherapy is basically an agent for local or regional tumor control, it is logical to believe that error in target volume assessment or its localization will cause radiotherapy failures.

CHAPTER-3

Treatment simulation:

Patient simulation was initially developed to ensure that the beams used for treatment were correctly chosen and properly aimed at the intended target. Presently, treatment simulation has a more expanded role in the treatment of patients consisting of:

- Determination of patient treatment position.
- Identification of the target volumes and organs at risk.
- Determination and verification of treatment field geometry.
- Generation of simulation radiographs for each treatment beam for comparison with treatment port films.
- Acquisition of patient data for treatment planning.

The simplest form of simulation involves the use of port films obtained on the treatment machines prior to treatment in order to establish the treatment beam geometry. However, it is neither efficient nor practical to perform simulations on treatment units. Firstly, these machines operate in the megavoltage range of energies and therefore do not provide adequate quality radiographs for a proper treatment simulation, and secondly, there is a heavy demand for the use of these machines for actual patient treatment, so using them for simulation is often considered an inefficient use of resources.

There are several reasons for the poor quality of port films obtained on treatment Machines, such as: Most photon interactions with biological material in the megavoltage energy range are Compton interactions that are independent of atomic number and that produce scattered photons that reduce contrast and blur the image. The large size of the radiation source (either focal spot for a linear accelerator or the diameter of radioactive source in an isotope unit) increases the detrimental effects of beam penumbra on the image quality. Patient motion during the relatively long exposures required and the limitations on radiographic technique also contribute to poor image quality.

For the above reasons, dedicated equipment for radiotherapy simulation has been developed.

Patient treatment position and immobilization devices:

Depending on the patient treatment position or the precision required for beam delivery, patients may or may not require an external immobilization device for their treatment.

Immobilization devices have two fundamental roles:

1. To immobilize the patient during treatment.
2. To provide a reliable means of reproducing the patient position from simulation to treatment, and from one treatment to another.

The simplest immobilization means include masking tape, Velcro belts, or elastic bands. The basic immobilization device used in radiotherapy is the head rest, shaped to fit snugly under the patient's head and neck area, allowing the patient to lie comfortably on the treatment couch.

Figure: Headrests used for patient positioning and immobilization in external beam radiotherapy.

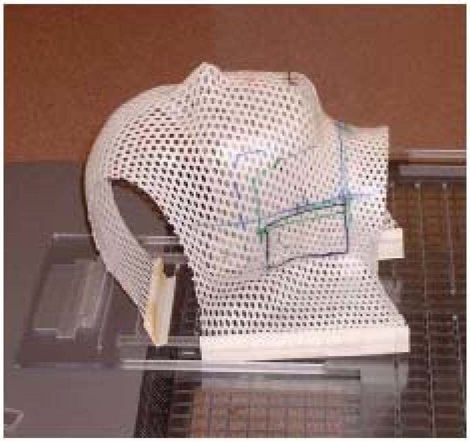

Figure: Plastic mask used for immobilization of brain or head and neck patients.

Conventional treatment simulators:

Simulators:

Simulators provide the ability to mimic most treatment geometries attainable on megavoltage treatment units, and to visualize the resulting treatment fields on radiographs or under fluoroscopic examination of the patient. They consist of a gantry and couch arrangement similar to that found on isocentric megavoltage treatment units, with the exception that the radiation source in a simulator is a diagnostic quality x-ray tube rather than a high-energy linac or a cobalt source.

Some simulators have a special attachment that allows them to collect patient cross-sectional information similarly to a CT scanner; hence, the combination is referred to as a simulator-CT. Figure below shows a photograph of a conventional treatment simulator. The photons produced by the x-ray tube are in the kilo voltage range and are preferentially attenuated by higher Z materials such as bone through photoelectric interactions. The result is a high quality diagnostic radiograph with limited soft-tissue contrast, but with excellent visualization of bony landmarks and high Z contrast agents. A fluoroscopic imaging system may also be included and would be used from a remote console to view patient anatomy and to modify beam placement in real time.

Figure: A photograph of a conventional treatment simulator.

Localization of target volume and organs at risk:

For the vast majority of sites, the disease is not visible on the simulator radiographs, therefore the block positions can be determined only with respect to anatomical landmarks visible on the radiographs (usually bony structures or lead wire clinically placed on the surface of the patient).

Determination of treatment beam geometry:

Typically, the patient is placed on the simulator couch, and the final treatment position of the patient is verified using the fluoroscopic capabilities of the simulator (e.g., patient is straight on the table, etc.).

The position of the treatment isocenter, beam geometry (i.e., gantry, couch angles, etc.) and field limits are determined with respect to the anatomical landmarks visible under fluoroscopic conditions.

Once the final treatment geometry has been established, radiographs are taken as a matter of record, and are also used to determine shielding requirements for the treatment. Shielding can be drawn directly on the films, which may then be used as the blueprint for the construction of the blocks. A typical simulator radiograph is shown in Figure.

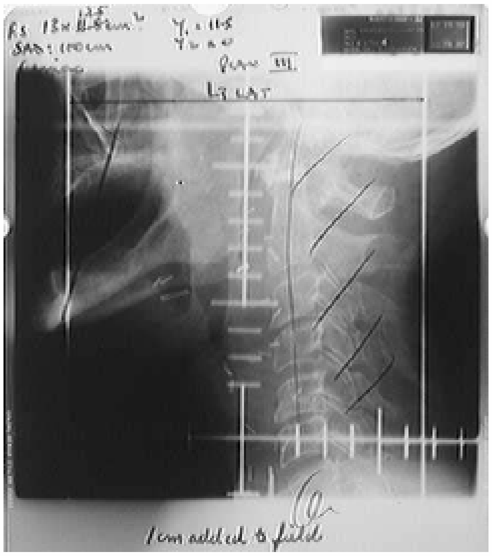

Figure: A typical simulator radiograph for a head and neck patient. The field limits and shielding are clearly indicated on the radiograph.

Treatment time port films are compared to these radiographs periodically to ensure the correct set up of the patient during the treatments.

Acquisition of patient data:

- After the proper determination of beam geometry, patient contours may be taken at any plane of interest to be used for treatment planning.
- Although more sophisticated devices exist, the simplest and most widely available method for obtaining a patient contour is though the use of lead wire.
- Typically, the wire is placed on a transverse plane parallel to the isocenter plane. The wire is shaped to the patient's contour, and the shape is then transferred to a sheet of graph paper.
- Some reference to the room coordinate system must be marked on the contour (e.g., laser position) in order to relate the position of the beam geometry to the patient.

CT Simulator:

Dedicated CT scanners for use in radiotherapy treatment simulation and planning are known as CT-simulators. The components of a CT-simulator include: a large bore CT scanner (with an opening of up to 85 cm to allow for a larger variety of patient positions and the placement of treatment accessories during CT scanning); room lasers allowing for patient positioning and marking; a flat table top to more closely match radiotherapy treatment positions; and a powerful graphics workstation, allowing for image manipulation and formation. An example of a modern CT-simulator is shown in Figure below.

Figure: A dedicated radiotherapy CT simulator. Note the flat table top and the large bore (85 cm diameter). The machine was manufactured by Marconi, now Philips.

CT Machine of our Hospital:

The CT Machine of our hospital is **SOMATON Emotion Duo** of SIEMENS MEDICAL installed on 01/08/2007. It is a third generation CT Machine having software version syngo CT 2006A.

Features:

- ✓ Rotate-Rotate movement.
- ✓ No translational motion.
- ✓ Mechanically coupled source & detector array rotate together.
- ✓ Wide fan beam to cover entire body.
- ✓ More number of detectors (more than 800 detectors).
- ✓ Scan time shorter than 5seconds.
- ✓ A single detector towards the end of array acts as reference detector.
- ✓ It has ergonomic enlarged gantry opening & its scan plane located only 35 cm from the gantry front.
- ✓ No limitations for patient set-up within 70 cm gantry opening & has the ability to scan at low table position thereby maximizing gantry "free space".
- ✓ New long-range gantry laser lights with position adjustment possible without opening gantry covers for easier installation & synchronization with room RTP lasers.
- ✓ Maximum KVp=130, Maximum mA=240.

CHAPTER-4

CT Simulation:

For simple computerized 2D treatment planning, the patient's shape is represented by a single transverse skin contour through the central axis of the beams. This contour may be acquired using lead wire or plaster cast at the time of simulation.

The patient data requirements for more sophisticated treatment planning systems such as those used in conformal treatment planning are more elaborate than those for 2D treatment planning. They include the following:

- The external shape of the patient must be outlined for all areas where the beams enter and exit (for contour corrections) and in the adjacent areas (to account for scattered radiation).
- Targets and internal structures must be outlined in order to determine their shape and volume for dose calculation.
- Electron densities for each volume element in the dose calculation matrix must be determined if a correction for heterogeneities is to be applied.

- Attenuation characteristics of each volume element are required for image processing.

- The nature and complexity of data required for sophisticated treatment planning limits the use of manual contour acquisition. At the very best, patient external contour information can be obtained through this method.
- Transverse CT scans contain all information required for complex treatment planning and form the basis of CT-simulation in modern radiotherapy treatment.

Computed tomography-based patient data acquisition:

With the growing popularity of computed tomography (CT) in the 1990s, the use of CT scanners in radiotherapy became widespread. Anatomical information on CT scans is presented in the form of transverse slices, which contain anatomical images of very high resolution and contrast, based on the electron density.

- CT images provide excellent soft tissue contrast allowing for greatly improved tumour localization and definition in comparison to conventional simulation.

- Patient contours can be obtained easily from the CT data; in particular, the patient's skin contour, target, and any organs of interest.

- Electron density information, useful in the calculation of dose inhomogeneities due to the differing composition of human tissues, can also be extracted from the CT dataset.

- The target volume and its position are identified with relative ease on each transverse CT slice. The position of each slice and therefore the target can be related to bony anatomical landmarks through the use of scout or pilot images obtained at the time of scanning.

- Pilot or scout films relate CT slice position to anterior-posterior and lateral radiographic views of the patient at the time of scanning. They are obtained by keeping the x-ray source in a fixed position and moving the patient (translational motion) through the stationary slit beam. The result is a high definition radiograph which is divergent on the transverse axis, but non-divergent on the longitudinal axis.

- The target position relative to the bony anatomy on the simulator radiographs may then be determined through comparison with the CT scout or pilot films keeping in mind the different magnifications between the simulator films and scout films.

- This procedure allows for a more accurate determination of tumour extent and therefore more precise field definition at the time of simulation.

- If the patient is CT scanned in the desired treatment position prior to simulation, the treatment field limits and shielding parameters may be set with respect to the target position, as determined from the CT slices.

- The treatment beam geometry, and any shielding required can now be determined indirectly from the CT data.

- The result is that the treatment port more closely conforms to the target volume, reducing treatment margins around the target and increasing healthy tissue sparing.

Virtual Simulation:

- Virtual simulation is the treatment simulation of patients based solely on CT information.

- The premise of virtual simulation is that the CT data can be manipulated to render synthetic radiographs of the patient for arbitrary geometries.
- These radiographs, known as digitally reconstructed radiographs (DRRs), can be used in place of simulator radiographs to determine the appropriate beam parameters for treatment.

- The advantage of virtual simulation is that anatomical information may be used directly in the determination of treatment field parameters.

Virtual simulation procedure:

- The CT simulation commences by placing the patient on the CT-simulator table in the treatment position. The patient position is verified on the CT pilot or scout scans.

- Prior to being scanned, it is imperative that patients be marked with a reference isocenter. Typically, a position near the center of the proposed scan volume is chosen, radio-opaque fiducial markers are placed on the anterior and lateral aspects of the patient (with the help of the positioning lasers to ensure proper alignment), and the patient is tattooed to record the position of the patient's fiducial markers to help with the subsequent patient setup on the treatment machine.

- This "reference" isocenter position can be used as the origin for a reference coordinate system from which our actual "treatment" isocenter position can be determined through translational motions of the couch.

- Target structures and organs of interest can be outlined directly on the CT images using tools available in the virtual simulation software.

CT Simulation Protocol:

CT simulation is a process used by the radiation therapy team to determine the exact location and size of the area to be treated. This is done in a room that contains a narrow, movable table and special X-ray equipment. During simulation, the patient will lie on the table. The radiation therapist will position the patient and then watch through a window while the CT scanner takes pictures or "slices" of the treatment site. The radiation oncologist looks at the cancerous area with the radiation therapist. The must lie still during simulation so the exact area to be treated can be pinpointed. Relaxing during simulation ensures consistent, accurate treatments. If the patient is already taking pain medication, the patient can take it before coming for the appointment and can even bring someone with them in case they need it. The radiation therapist may use special pillows, pads, or other devices to help hold the patients body in the proper position. Sometimes contrast material (liquid with dye in it) may be swallowed or injected into the patient's body so that the internal organs are easier to view on the CT scan. After the radiation oncologist locates the area to be treated, the radiation therapist will outline the treatment field (area to be treated) on the patient's skin. These tiny, permanent dots will be used as a guide for correct positioning during the treatments. Simulation usually lasts between 15 and 30 minutes; however, the patient may need additional simulation after treatment has begun. After the simulation, dosimetry is performed.

HOW WE DO THE CT SIMULATION IN OUR HOSPITAL:

- First we place the patient in the CT couch with all the required immobilization devices.
- One lead marker or fiducial marker is placed on the patient’s anterior body surface & other two are placed laterally using the laser beams.
- The images are taken.
- Viewing the images we locate the tumour position.
- We use the markers as reference points in a defined co-ordinate system based on the patients body.
- Based on the co-ordinate system we find out the exact location of the tumour.
- Using the moving lasers (as the movement of the couch in CT machine & the treatment unit is not same therefore moving lasers are used) we again place the markers on the exact tumour location & also we place the markers laterally in a new position as obtained from the CT images.
- There are three moving lasers: one sagitall with single laser source & two lateral lasers with two sources form a cross-wire in both sides.
- Again images are taken & confirmation of the exact location is made.
- Based on those markings we place the patient on the treatment couch.

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