This research work consists the experimental and observational objectives. Experimental research work was performed on the tissue equivalent phantom which was fabricated locally with average dimensions of the organs in thoracic cavity. The observational research work was carried out on the CT data of the carcinoma lung patients received the Endobronchial Brachytherapy Treatment in High Dose Rate Brachytherapy Machine. This was a Cross sectional observational Study on patients of lung carcinoma during the period of three years. This study was conducted in the department of Radiation Oncology Cancer Research Institute Himalayan Institute of Medical Sciences, Swami Rama Himalayan University Jolly Grant Dehradun Uttarakhand. Ethical Clearance was obtained from the Institutional Ethical Committee (IEC) with approval no SRHU/HIMS/E-1/2023/54.

INCLUSION AND EXCLUSION CRITERIA:

Patients of carcinoma lung were included in the study with the endobronchial tumor in the primary and secondary bronchus. Carcinoma lung with the tumor in the plural and peripheral part of the lung other than primary and secondary bronchus patients were excluded in the study.

STATISTICAL ANALYSIS:

Descriptive statistics of analysis was performed after entering all the data in the MS Office excel sheet 2007. The same set of data was also analyzed using SPSS software version 22. Graphical representation was used to understand the results clearly wherever desirable.

If the $p<0.05$, then the hypothesis was statistically significant and if $p>0.05$, then hypothesis was statistically insignificant.

The Sample size for the secondary objective was calculated through the formula:

$$n = \{(Z_{\alpha/2})^2 Pq\}/ l^2$$

Where, α= 5% level of significance

P= 50% {Unknown exposure}

l = take 25% relative precision

The secondary objective sample size was 61 (Samples) calculated by the above formula. Therefore, we included ninety endobronchial treatment sessions as samples in the observation research work in secondary objective of thesis.

A. MATERIAL

1.1 HIGH DOSE RATE BRACHYTHERAPY:

1.1.1 HDR BRACHYTHERAPY FACILITY DESIGN:

The HDR Brachytherapy Facility Design consist of an Operating System room, treatment room, treatment planning room, imaging room and recovery room as per the regulation of the International Atomic Energy Agency (IAEA) (TECDOC-1040 & 1257) [52, 53]. Operating and recovery rooms are required when implant technique performed under anesthesia. Imaging room is needed to get the patient's CT scan images for treatment planning and visualize the dose distribution. Treatment planning room is used to perform planning and get optimized plan for execution on the machine. Treatment room is designed to keep the HDR machine with adequate shielding for minimizing exposure outside the wall and door interlocking system in association with Last-Man-Out Switch (LMO). One control console room is located

adjacent to the treatment room where close circuit camera system is present to monitor patient during treatment and control system to operate the machine. One gamma zone radiation monitoring device is present at the entry of the machine room inside.

1.1.2 REMOTE AFTERLOADING SYSTEM:

The microselectron HDR V3 brachytherapy remote after loading (RAL) unit (Nucletron Pvt. Ltd. make) is available for the treatment execution. RAL unit automatically administers a radioactive source directly in to the tumor, thereby minimizing radiation dose to the surrounding healthy tissue and reducing radiation exposure to the Hospital Staff. The radioactive sources Co-60, Cs-137 and Ir-192 are being used in brachytherapy (Table 1). A radioactive source Ir-192 is having high specific activity therefore it is widely used in the HDR RAL unit[2] as compared to the Co-60 and Cs-137 which are having long half life but low specific activity. High specific activities allow us to make a radioactive source of small size which is beneficial in case of Interstitial and Intraluminal brachytherapy implants[54]. In HDR-RAL unit, Ir-192 source is used with cylindrical shape and encapsulated with stainless steel with activity less than 10 Curie (<10 Ci).

S.N.	Radionuclide Name	Energy (MeV)	Half Life	HVL in lead (mm)
1.	Cs-137	0.662	30 Years	5.5
2.	Co-60	1.25 (1.17 & 1.33)	5.26 Years	11.0
3.	Ir-192	0.38 (0.14 to 1.06)	73.8 Days	2.5

Table 1: Physical characteristic of radionuclide used commonly in RAL Unit

The dimension of HDR Ir-192 brachytherapy source capsule [Nucletron Pvt. Ltd. make] is 4.5mm length and 0.9mm diameter, shown in Figure (3)[43]

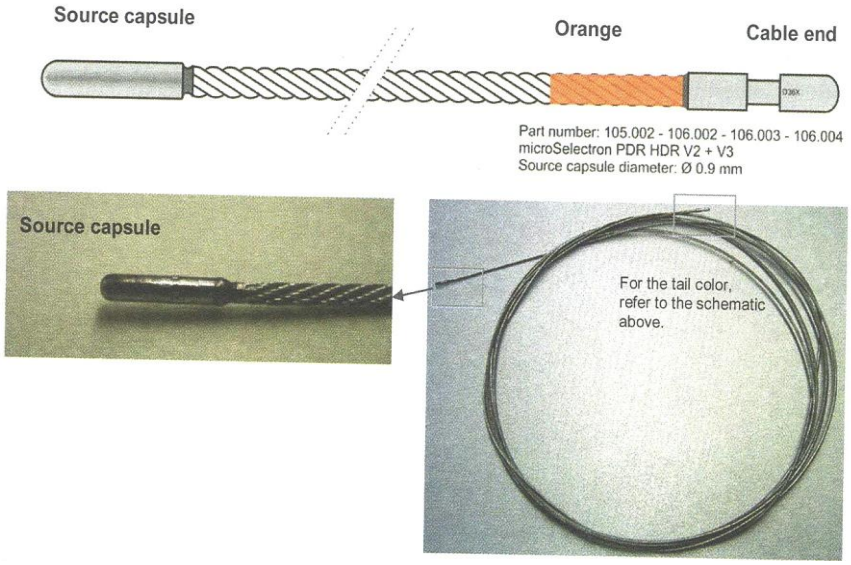


Figure 3: Design of HDR Ir-192 Brachytherapy Source capsule (Nucletron Pvt. Ltd. Make)

The AAPM report No. 41 highlighted four essential features of all remote after - loaders:

1. "A primary storage safe to contain source when not in use".

2. “A mechanism to transport the source from storage to applicator in the patient”.

3. “A system to maintain source in the applicator for a dwell time period”.

4. “A mechanism, to return the source back to the storage safe at the end of the treatment and during power failure or in other emergencies”.

The remote after loader consist a computer-controlled stepper motor to drive a radioactive source from its safe shielded position to the treatment position into the applicator via transfer tubes. RAL unit is having 30 channels to facilitate the source entry and move into the applicator. Ir-192 radioactive source encapsulated is welded at one end of flexible cable. There is a check cable in the RAL unit, which is same as the source fixed in its own drive cable. The aim of a check cable is to run just before the main radioactive source moved into the applicator and check the connections and also for any obstruction in the treatment. A single source is used in the RAL unit with a multiple dwell position and source can move with a step size 2.5mm, 5.0mm and 1.0cm depending upon the treatment length and channels utilized in a patient, this design remove the need of multiple sources to be present in the single unit.

1.1.3 SOURCE STRENGTH SPECIFICATION:

The source strength is helpful in assessing the dose distribution in a tissue from a brachytherapy source. Initially, the source strength specification quantity of radium is mass of radionuclide with unit milligram of radium. Later for the other sources it was defined as equivalent mass of Radium. Another quantity of source specification

was activity of the source. Activity was the rate of disintegration of source, having unit curie (Ci). Initially curie was defined as activity of 1 gram of radium or $3.7x10^{10}$disintegration per second. Becquerel (Bq) [disintegration per second] is SI unit of activity. The activity and exposure rate constant (Γ_{δ}) product is proportional to the exposure rate at a point, have a unit $Rm^2h^{-1}Ci^{-1}$. Apparent activity was introduced for source specification, which was defined as "the activity of an imaginary point source of a same radionuclide which produces the same exposure rate as that of a sealed source at 1 m distance". A new quantity to specify the γ ray emitting source is Reference Air KERMA Rate, which is explained as the Air KERMA Rate at a reference distance of 1 meter along the perpendicular bisector of longitudinal axis of the source in air with attenuation and scattering correction with unit μGyh^{-1}. AAPM has recommended that the radioactive source strength specification is done with the use of Air KERMA strength (AKS) for brachytherapy[55]. As per the AAPM and ABS the AKS should be used in treatment delivery process in brachytherapy including source ordering, dose calculation, treatment planning, treatment prescription and implant documentation.

1.2 TREATMENT PLANNING SYSTEM (TPS):

1.2.1 DOSE CALCULATION ALGORITHM IN TPS:

The algorithm for dose calculation used in TPS for brachytherapy is Sievert Integral and AAPM TG-43. 3D TPS is dedicated for routine HDR brachytherapy treatment planning.

(i) SIEVERT INTEGRAL METHOD:

Dose-rate distribution nearby the source was calculated using Sievert integral model[56]. In this model, a line source divided in small parts and applies the Inverse-Square-Law and correction oblique filtration of photon through source capsule. Exposure rate at a point P from a line source can be determined[57] with

$$Rp = (A.\ \Gamma_x)/yL \int_{\theta_1}^{\theta_2} e^{-(\mu t sec\theta - \mu t)} d\theta$$

Where, A = apparent activity of the source,

Γ_x = Air KERMA Rate constant

L = source active length

y = perpendicular distance between the source axis and point P

θ_1, θ_2 = Angles subtended by the active ends of the source at point P

t = thickness of filtered material and

μ = linear attenuation coefficient of the filtered material

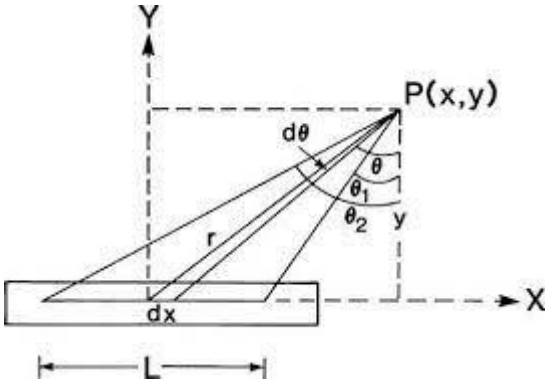


Figure 4: Sievert integral model for dose calculation in brachytherapy

The Sievert integral method considers the effects of filtration and inverse square law to provide the distribution of exposure rate in air. Some additional factors need to be considered like attenuation and scattering in the surrounding tissue while a source

implanted in tissue. A factor "Roentgen to RAD conversion" is used to change the exposure rate into absorbed dose rate when calculated at a point in the tissue.

(ii) AAPM TG-43 METHOD:

The normal dosimetric model of dose calculation uses the exposure rate constant and tissue attenuation factors. The tissue attenuation factors for low energy sources are difficult to measure. The dose calculation formalism proposed by the ICWG (Interactive collaborative working group, USA) and accepted by the AAPM Task Group No. 43 Radiotherapy committee[33]. In this formalism dose rate in tissue equivalent medium is used for a source. In this formalism the effect of radionuclide distribution in the capsule is taken into account through geometric factor G (r, θ); the effect of absorption and scattering in the capsule and tissue taken into account by a radial dose function g(r) and all other directions by an angular anisotropy factor F (r, θ). As per the recommended formalism, the dose to a point can be calculated from the numerical values of measurable parameters, dose rate constant (Λ), g(r) and F (r, θ) where Λ is an absolute quantity and g(r) & F (r, θ) are relative quantities.

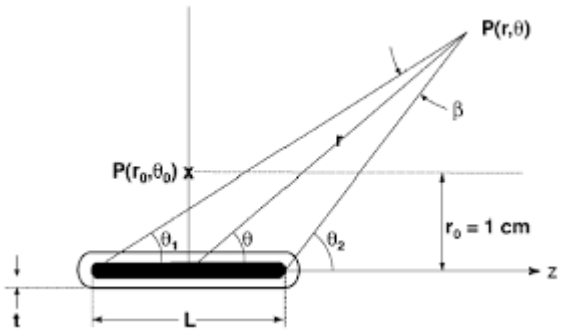


Figure 5: Dose calculation formalism TG-43 of AAPM

The dose rate, D (r, θ), at point P with polar coordinates (r, θ) in a medium (e.g., water) from the center of a source of air kerma strength S_K can be expressed as

$$\dot{D}(r,\theta) = \Lambda S_K \frac{G(r,\theta)}{G(1,\pi/2)} F(r,\theta)\, g(r)$$

Where Λ is the dose rate constant, defined as the dose rate per unit air kerma strength (U) at 1 cm along the transverse axis of the seed and has units of cGy/h/U; the dose rate constant, Λ, depends on the type of source, its construction, and its encapsulation.

$G(r, \theta)$ is the geometry factor (cm^{-2}) that accounts for the geometric falloff of the photon fluence with distance from the source and depends on the distribution of radioactive material.

$F(r, \theta)$ is the anisotropy factor normalized at θ = л/2 (transverse axis), with the geometric factor factored out;

The anisotropy factor accounts for the angular dependence of photon absorption and scatter in the encapsulation and the medium.

The radial dose function, $g(r)$, accounts for the radial dependence of photon absorption and scatter in the medium along the transverse axis.

Again, the geometric factor is factored out from the dose rates in defining $g(r)$.

Because of the numerous source models available commercially, the user must make sure that the dose calculation algorithm and the input source data are consistent with the AAPM TG-43U1 protocol.

1.2.2 ONCENTRA MASTER PLAN (OMP) TPS:

It comprises a set of individual modules of treatment planning for external beam radiotherapy and brachytherapy. Oncentra-Master-Plan is designed for DICOM integration, connectivity and flexibility.

Brachy Planning (BP) handles the creation of a brachy treatment plan, including source definition, catheter reconstruction, source dwell position activation, dose normalization, dose optimization [Inverse Planning Simulated Annealing (IPSA)], dose prescription, plan evaluation, plan reporting and plan exporting.

The Brachy Planning activity allows the user to create a brachy treatment plan, which can be executed on a remote afterloading system (Nucletron Make) with a specific radioactive source for HDR brachytherapy.

The catheters are placed in the patient. Patient images are acquired with an imaging device. In Oncentra Master-Plan, the acquired images are imported and attached to the patient data. Using the Anatomy Modeling activity, regions of interest (target, organs at risk) can be defined on the images.

In the Brachy Planning activity, the brachy treatment plan is made. The catheters are reconstructed on the image data set(s). The treatment plan is made using a specific set of tools (e.g., activation of source dwell positions, dose optimization, and plan evaluation). The final treatment plan is approved by an authorized person and exported to the remote afterloading system.

The Oncentra Master plan TPS consist a software with functions like source definition, catheter reconstruction, activation of source dwell positions, defining points, dose normalization, dose optimization, dose prescription, plan evaluation, plan reporting and plan exporting.

The dose calculation methods used in brachytherapy TPS, most commercially is remains the basic compared to External Beam Radiotherapy TPS. The modern HDR brachytherapy treatment planning systems (TPS) based on dose optimization software and the complex treatment planning process requires the dosimetric verification of HDR treatment planning system (TPS). The dosimetric verification of TPS calculated doses by experimental and Monte Carlo simulation methods have been reported in the literature [58, 59].

The American Association of Physicists in Medicine (AAPM), Task Group 43 (TG-43) formalism used in the TPS for dose calculation, which includes different methods of optimization for the dose distribution such as geometrical/graphical optimization and adjustment of dwell positions and dwell times [33, 34].

1.2.3 CT IMAGING FOR BRACHYTHERAPY TPS:

Treatment planning system of brachytherapy uses computed tomography (CT) image data set for dose calculation and planning purpose with the help of ultrasound and Magnetic Resonance Image (MRI). The introduction of three-dimensional imaging improves the dose calculation and distribution in a tissue equivalent medium which modify the algorithm for different inhomogeneities present in the human body.

A Computed Tomography machine is used to acquire the images of the patient who has already gone through the procedure of applicator or catheter insertion in operation theater (OT) by the expert physician. To visualize the applicator/ catheter in the CT images of the patient a radio opaque marker needs to be placed into the applicator/ catheter. This is visualized in the CT images of the patient and the

applicator/ catheter can be reconstructed easily. According to the disease or tumor volume the source positions will be given and dose distribution can be seen in the treatment planning system. The target volume and organs at risk delineated on the CT image data set of the patient. CT images help us to visualize the tumor dose coverage and doses to the organs at risk nearby the tumor volume. The plan is saved in the database of the TPS so that the total doses to OARs and tumor volume can be found out and record maintained for future aspects.

2. RADIOCHROMIC FILM DOSIMETRY SYSTEM:

2.1 RADIOCHROMIC FILM DOSIMETER:

Radiochromic dosimeters are solid state detectors in the sense that the structural properties of their crystalline solid undergo a change when exposed to radiation. The polymerization results in a color (chromatic) change. Radiochromic dosimeters can exist in various forms such as liquids, gels, films and pellets. Radiochromic films are increasingly being used in radiotherapy centers for the measurement of 2D dose distributions; this is due partly to improved dose sensitivity of newer radiochromic films but also to decline in the use of processor based radiographic film. International Specialty Products (ISP) manufacturers a range of radiochromic films under the product name Gafchromic. The difference between each type of film relates to whether it is constructed with a single or double active layer film, if it is reflective or transmissive film, its physical dimension, and the specific chemical composition of the active layer. EBT3 is the latest model of Gafchromic and widely used in the radiotherapy dosimetry[60].

GAF-Chromic EBT-3 Film is used to measure the absorbed dose in photon beam of ionizing radiation for high energy in radiotherapy. EBT3 films having dynamic dose range from 0.2Gy to 10Gy for use in radiotherapy. These are suitably used in IMRT, VMAT and Brachytherapy etc. dosimetric applications.

The EBT3 film cross sectional view is shown in Figure 6. The film structured as one active layer approximate 28μm thick in the middle of two side layers of matte polyester substrates of 125μm thickness of each. The middle active layer consists the stabilizers, marker dye and some active components which makes the response of the film energy independent[61].

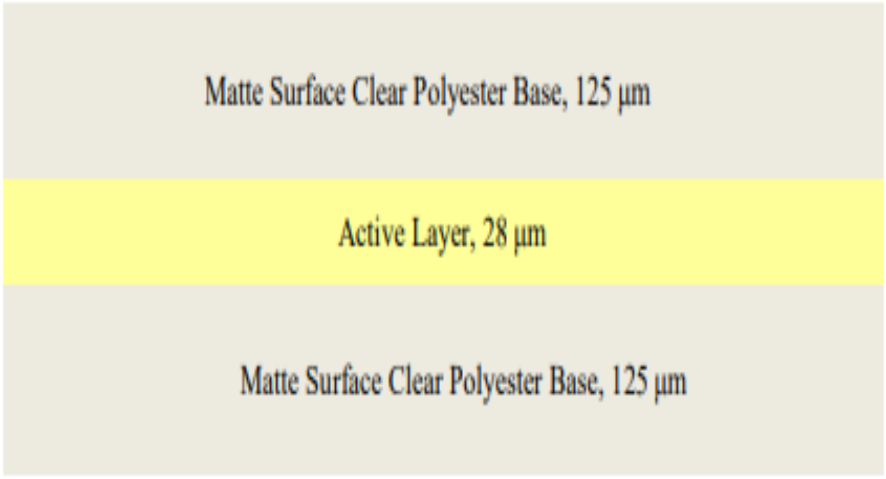


Figure 6: Structure of GAF-Chromic Dosimetry EBT3 Film

Some key features of GAF-Chromic EBT3film in technical form:

- Dynamic and optimum dose range 0.1 Gy to 20 Gy and 0.2 Gy to 10 Gy respectively,
- Real-time development after exposure;
- Close to tissue-equivalent;
- Spatial-resolution high

- Sensitivity to visible / UV light decreases
- Constant up to 60°C temperatures

2.2 EPSON FLAT BED SCANNER & SOFTWARE:

Epson Expression 11000XL Flatbed Scanner is connected with the computer system through USB. Epson delivers the Expression 11000 XL with its own scan software EPSON-Scan. That is simple scan software which can scan both documents and films. The Epson Expression 11000 XL is perfectly suited for scanning film material. It has reading area of 310X437mm2. It can read films in transmission or reflection mode up to a color depth of 48 bits, a maximum resolution of 2400 dpi and maximum optical density of 3.8. As per the recommendations, samples were scanned in landscape orientation, in transmission mode and red color channel of the scanner.

2.3 FEBRICATION OF TISSUE EQUIVALENT PHANTOM:

A tissue equivalent phantom was fabricated locally from tissue equivalent material with effective atomic number 6.57 × 1023 electrons/g and electron density of 3.36 × 1023 electrons/g. Tissue substitutes for lungs two polyurethane foam (density 0.048g/cm^3) of cubic shape having almost similar density to lungs, for soft tissue PMMA (density 1.18g/cm^3) and for bone DELRIN (Polyoxymethylene) material (density 1.41g/cm^3) were used. The actual tissue densities present in the human body and substitute material used to fabricate the phantom is shown in table 2.

S.N.	ORGAN	SUBSTITUTE MATERIAL	DENSITY	
			SUBSTITUTE	ACTUAL
1.	Lungs	Polyurethane foam	0.42g/cm^3	0.62 g/cm^3
2.	Soft Tissue	PMMA	1.18g/cm^3	1.04 g/cm^3
3.	Bone	DELRIN (Polyoxymethylene)	1.41g/cm^3	1.14 g/cm^3

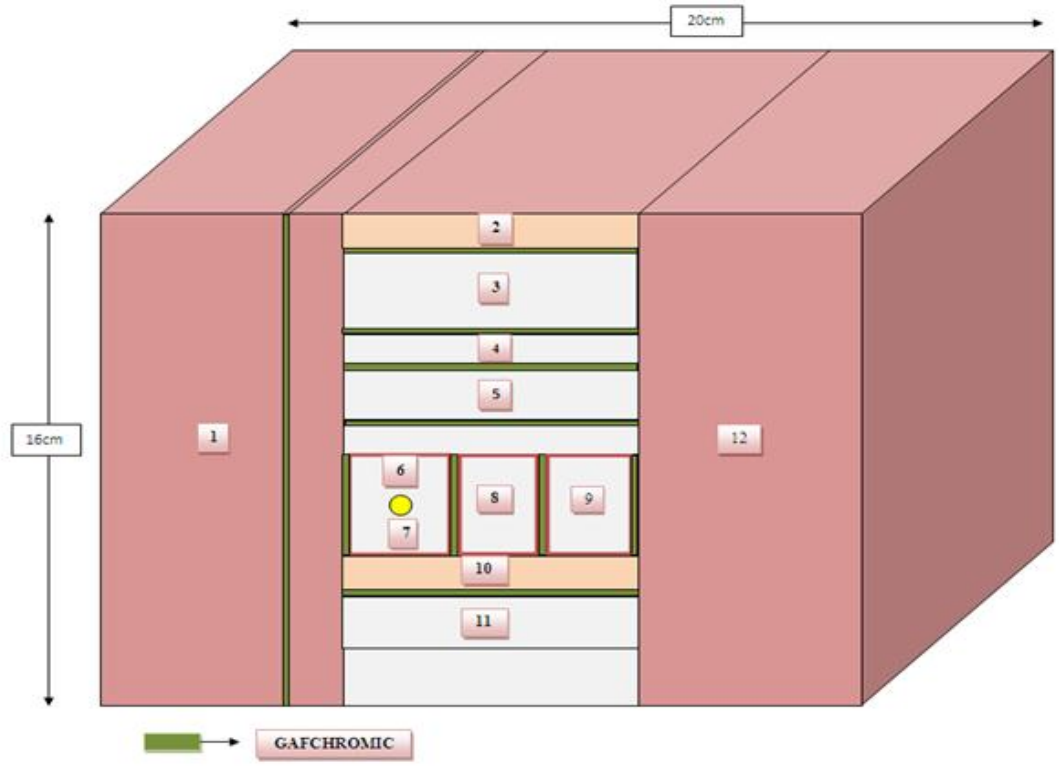
Table 2: Showing tissue densities used in the phantom fabrication

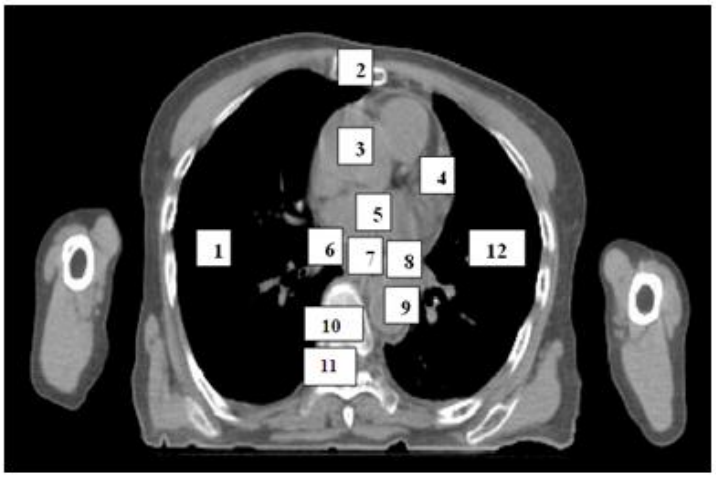
A phantom mimicking endobronchial brachytherapy treatment was locally fabricated using tissue equivalent material along with suitable density inserts for bone and lung tissue. For this purpose, treatment plans of fifteen patients of EBBT treatment were randomly selected and dimensions of the target volume and OARs were recorded. The average values of dimensions of each organ/ structure were used to create corresponding structure in the phantom. The actual shape of the structure was not easy to fabricate and positioning of film dosimeters in it for dosimetry therefore the structure's actual shape was transformed to the cubical shape corresponding to the structure's dimensions.

The locations for the films and cavity for source catheter were defined properly at surface of the organ at risk and in the target volume respectively (Figure 7).

The design of the phantom was shared with the phantom fabricator along with the details of the material equivalent to tissue. The fabricator made the phantom according to the defined dimensions. The physical verification of dimensions especially the cavity (hole) created for source catheter placement and Radiochromic (Gafchromic) film positioning at the designated locations in the phantom. After

checking all the parameters of Phantom, next step was to perform the imaging of the phantom for brachytherapy planning.





OARs Name	OARs N
IPSILATERAL LUNG	1
STERNUM	2
PULMONARY TRUNK & ASCENDING AORTA	3
CORONARY ARTERY	4
HEART	5
TARGET	6
SOURCE CATHETER	7
ESOPHAGUS	8
DESCENDING AORTA	9
VERTIBRA Body	10
SPINAL CORD	11
CONTRALATERAL LUNG	12

Figure 7: Diagram of the locally fabricated Tissue Equivalent Phantom correlating with thoracic cavity axial image

2.4: IMAGE PROCESSING & ANALYSIS SOFTWARE:

Image-J software was used to analyze the scanned films in the scanner. Image-J is image processing and analysis software for single image or stack of various formats including TIFF, GIF, JPEG etc. It was having multiple options and features to analyze the film and pixel values help us to find out the optical density within the irradiated area in the scanned film.

B. METHODS

3. EXPERIMENTAL DOSIMETRY USING RADIOCHROMIC FILMS:

3.1 FILM CALIBRATION:

The Gafchromic Films (EBT3) of size 8"x10" with LOT number 06142101 were used in the study. The Films were cut down of 3x3cm^2 size with proper marking for orientation at the corner of film and placed in the safe area prior to use in order to achieve accurate results and avoid the affects of environmental condition.

The EBT3 film was calibrated in the TrueBeam Linear accelerator (Varian Medical System Pvt. Ltd. Make) as the machine was calibrated for 1MU to 1cGy at isocentre prior starting the film calibration process. Poly Meth Methyl Acrylate (PMMA) RW3 slab phantom was used in the film calibration and source to skin distance was set 95cm for field size 10X10cm^2. The films of 3x3cm^2 size were placed in the PMMA slab phantom at 5cm depth and irradiated with the monitor units corresponding to the dose values, 10, 20, 30, 40, 50, 60, 70, 80, 90, 100, 125, 150, 175, 200, 250, 300, 350, 400, 500, 600, 700 cGy. [Figure 8(a), 8(b)]

The irradiated film samples were allowed for post exposure growth of density for 48 hours. The films were scanned in the EPSON Expression 11000XL flatbed scanner [Figure 9(a), 9(b)]. A common protocol was adopted to ensure the same orientation of film samples during cutting and scanning. The scanning was performed according to the guidelines of American Association of Physicists in Medicine (AAPM) Task Group (TG) -55[62]. The scanned film samples were analyzed in Image-J software. To ensure homogeneity, the pixel values from a small area of the film were analyzed and its pixel value obtained. The obtained pixel value from the irradiated film and unexposed film was used to find out the Mean Optical Density (MOD) value.

Figure 8(a). Output measurement before EBT3 Film Calibration in TrueBeam Linac

Figure 8(b). EBT3 Film Calibration in TrueBeam Linac

Figure 8 (a) & 8 (b): Showing a Gafchromic EBT3 Film Dosimeter Calibration setup at TrueBeam Linac

Once we obtained the MOD for corresponding dose value, a graph was plotted between the dose and MOD, called calibration curve. This calibration curve was used in the analysis of EBT3 films used in brachytherapy dosimetry in phantom (Figure 11).

The irradiated films were scanned in the EPSON [Expression 11000XL] flatbed scanner and analysis was performed with the help of Image-J software. The pixel values of the irradiated films were found out and then Mean Optical Density (MOD) was calculated.

The film scan in EPSON Flat bed scanner was performed very carefully in respect to the film orientation during irradiation and placement at the time of scanning in the film scanner.

Figure 9(a). EPSON scanner used to scan the EBT3 Film

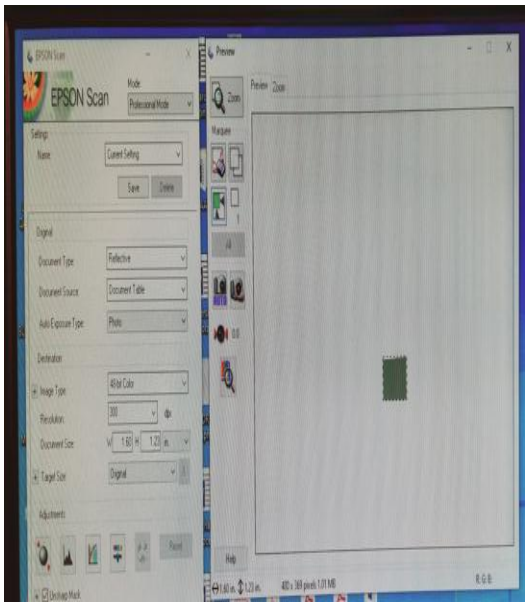


Figure 9(b). EPSON scanner Computer monitor used to scan the EBT3 Film

Figure 9(a) & 9(b): Showing an EPSON flatbed scanner used for the film scanning purpose

The calibration of EBT3 film was carried out in TrueBeam Linear Accelerator in the SAD (source to axis distance) setup and film size 3x3 cm^2 were irradiated with dose range 10cGy to 700cGy. The exposed EBT3 films were scanned (Figure 10) in the EPSON 11000XL Flat Bed scanner and analyzed with the Image-J software to find out the optical density corresponding to the irradiated dose (table 3).

S.N.	MOD	Dose
1	0.036117	10
2	0.064159	20
3	0.087436	30
4	0.118147	40
5	0.141435	50
6	0.161111	60
7	0.187402	70
8	0.203512	80
9	0.217729	90
10	0.234256	100
11	0.271136	125
12	0.300925	150
13	0.330877	175
14	0.353067	200
15	0.401794	250
16	0.446617	300
17	0.478495	350
18	0.516893	400
19	0.54695	500
20	0.566404	600
21	0.58	700

Table 3: Showing the MOD values for corresponding dose

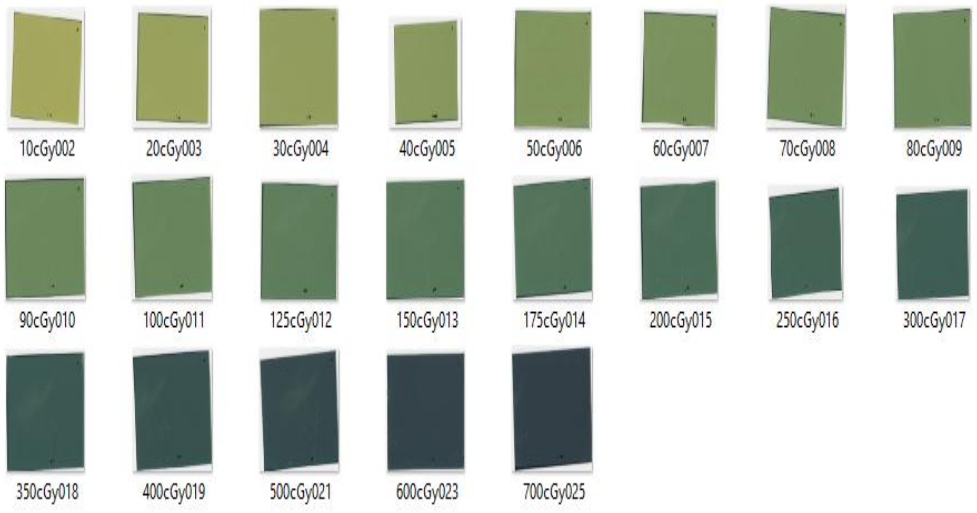


Figure 10: Irradiated EBT3 films exposed for the calibration

The pixel values of the irradiated films were found out and then Mean Optical Density (MOD) was calculated from the formula (Eq. 1)

$$MOD = Log_{10} (P_0/P) \qquad (1)$$

Where, P_0 is the obtained pixel-value from the film kept as background (Unexposed films) and P is the obtained pixel-value from the exposed film.

The relationship between MOD and dose was obtained, and plotted as a graph known as calibration curve (Figure 11). This calibration curve shows the relationship between the dose and respective MOD for a particular Lot of EBT3 film. The film response was nonlinear in nature and data were fit with a second order polynomial. Hence, the following equation was used in the conversion of film MOD to dose (D):

$$D_{(cGy)} = 1878.1(MOD)^2 - 66.88(MOD) \qquad [R^2 = 0.9673] \qquad (2)$$

Where, D= absorbed dose in cGy, MOD = mean optical density

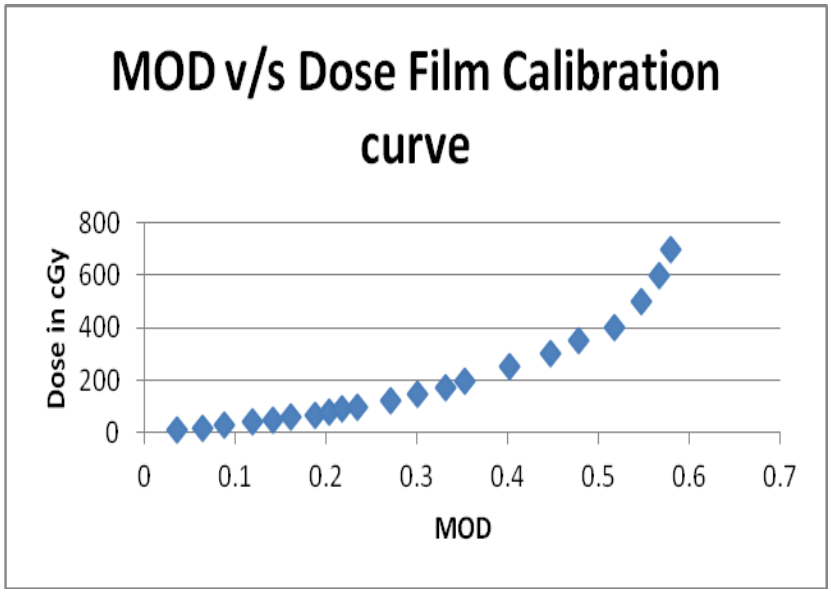


Figure 11: Calibration Curve for EBT3 Film Dosimeters

3.2 PHANTOM DOSIMETRY:

3.2.1 EXPERIMENTAL SETUP:

The phantom simulating the thoracic was composed of different parts which were connected to create a cuboid shape dimension 20x20x16 cm3. The central part (M) was a cuboid of 6x20x16cm3 dimension which consist 8 slabs and 5 cuboid shape blocks out of which one was having for source catheter cavity. Rest two side blocks of the phantom (L) & (R) were also cuboid in exact contact with central cuboid to provide a scattering medium and simulating left lung and right lung tissue (figure 12).

In the experiment setup arrangement, one film sample of EBT3 film was placed in between the slabs and blocks (figure 13) with green color. Few films samples were placed vertically on both side of the target structure cuboid at the surface of

esophagus, descending aorta, right lung and left lung surface. One film was placed at 2cm distance from the surface of the target structure cuboid parallel to each other.

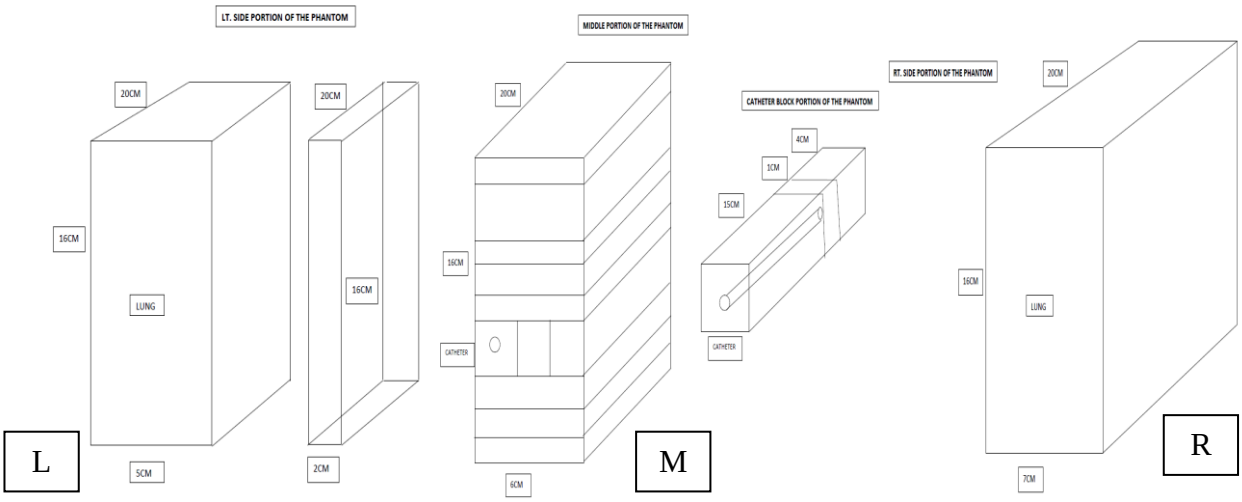
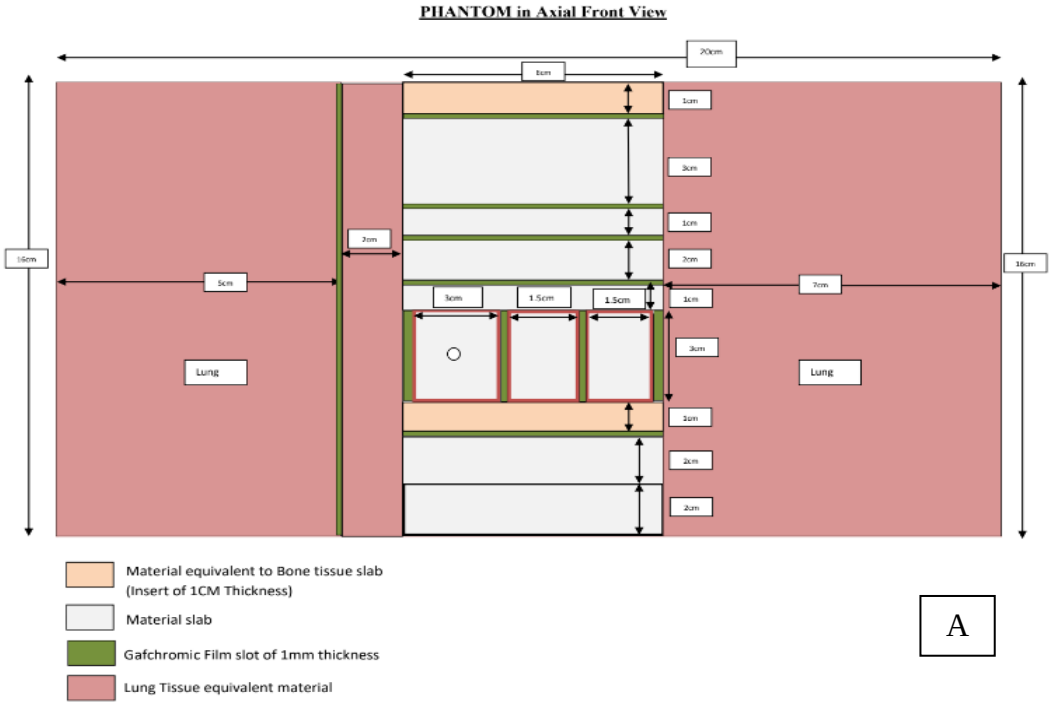


Figure 12: Schematic block diagram of the phantom for experimental setup



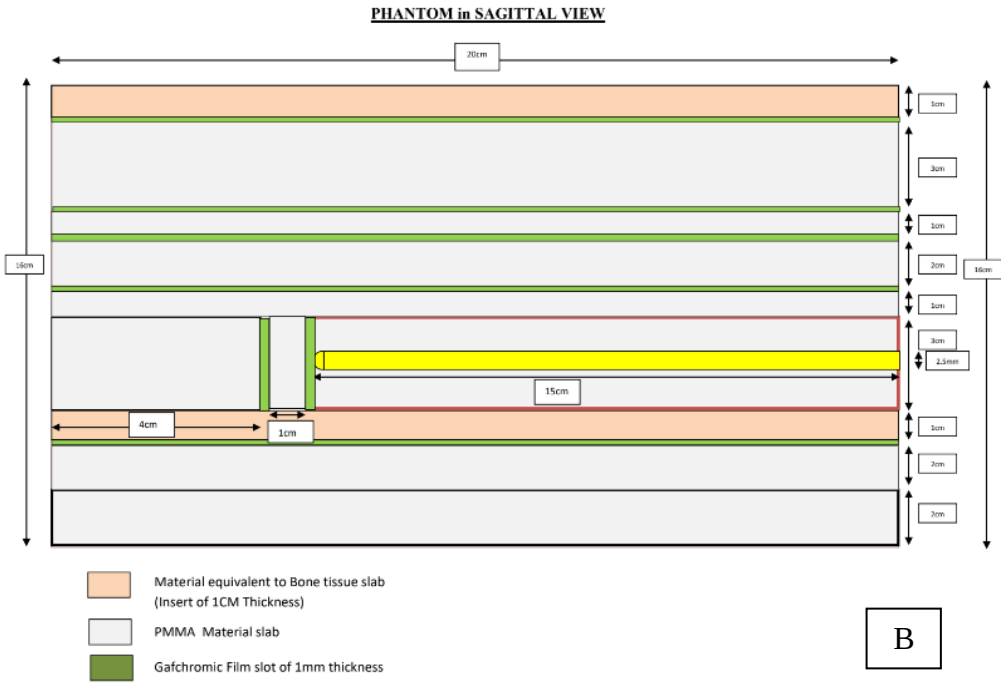


Figure 13: Schematic diagram of the phantom axial (A) and sagittal view (B) for experimental setup

3.2.2 IMAGE ACQUISITION:

The phantom was simulated and scanned in the PETCT scanner (GE Healthcare Pvt. Ltd.) with source catheter placed in the target slab in the phantom containing the dummy source to simulate the actual treatment geometry. During scan, the geometry of the phantom was made same as the irradiation condition to reproduce the same position to minimize the setup errors between the scanning and treatment execution. During the scan one set of films was placed at the measurement location and 6F Lumencare Intraluminal catheter of 150cm length was inserted into the grove made in the target slab and a source dummy was kept in it to visualize the catheter in CT scan images of the phantom[27]. “Source position simulator” [Nucletron Pvt. Ltd.

Make] used to measure the catheter length and check any obstruction in it. The CT scan of the phantom was acquired in the PET CT machine (GE Healthcare make) (Figure 14) and the images were send to OMP TPS for further planning on it.

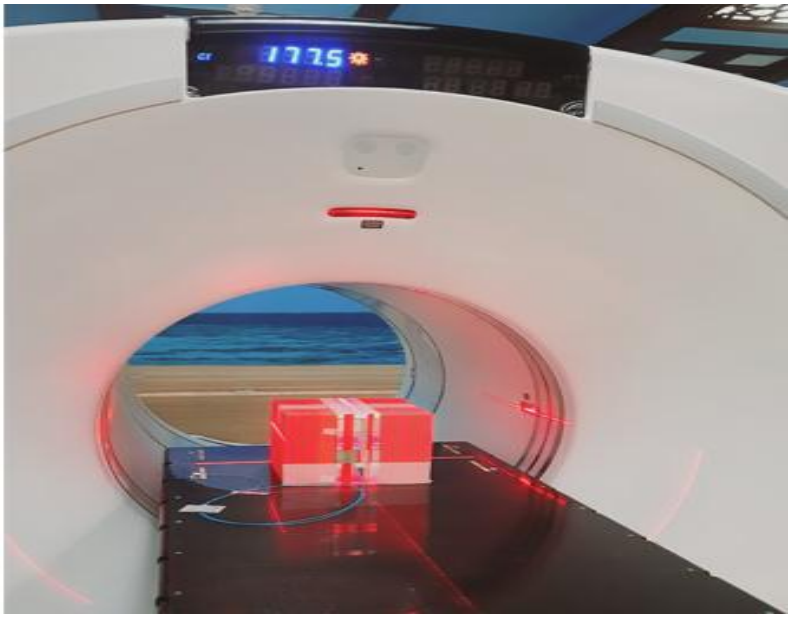


Figure 14: CT scan acquisition of the Thorax phantom fabricated locally

3.2.3 TREATMENT PLANNING AND EXECUTION:

The CT scan image data set of Phantom was imported in the TPS. Target volume and OAR's structures were delineated in the phantom in TPS. American brachytherapy society (ABS) recommendation was followed to generate a plan in brachytherapy module of TPS. The source dwell position loaded in the catheter was 5cm length and dose was 7Gy prescribed at 1cm diameter from the center of the source[27]. Dose calculation performed to get the dose distribution in the phantom (Figure 15)[40].

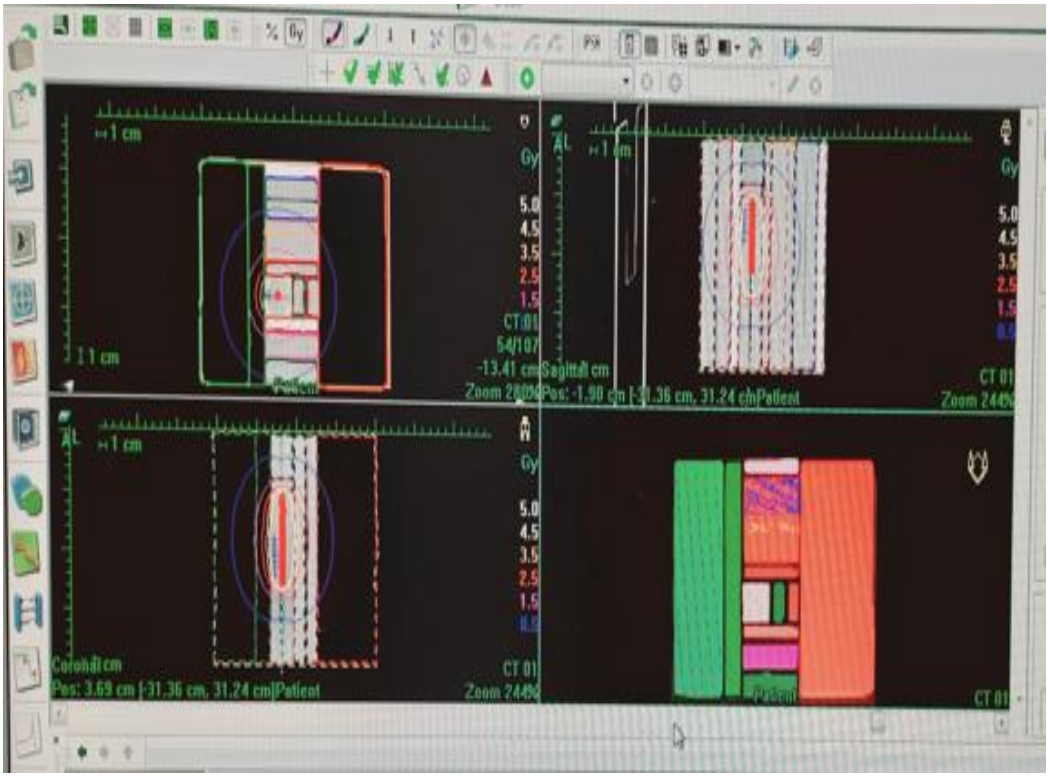


Figure 15: Showing EBBT treatment plan on Thoracic phantom

The GAFCHROMIC EBT3 Film was accurately cut down as per the size of its positioning in the phantom. At the time of film cutting, a very important point was its orientation which was taken care well. The GAFCHROMIC EBT3 Films were placed at the desired position in phantom for different organs at risk i.e. Heart, Spinal cord, Esophagus, Descending aorta, Pulmonary Trunk, Coronary Artery, Contra-lateral Lung (surface), and Ipsi-lateral Lung (surface and at 2-cm depth).

The treatment plan was executed in the brachytherapy machine (Figure 16) in same setup as the CT scan was acquired. Insert the Lumencare catheter in the phantom and connect the catheter with indexer of the machine. Select the plan in the control console and start the irradiation. The films positioned at the different locations in the phantom were irradiated in the microselectron High Dose Rate Machine with Ir-192

source as per the treatment plan created in the TPS on the scanned phantom. Once the irradiation completed the film positioned at different places in the phantom were taken out and kept in the envelope with clear marking of its position in phantom for corresponding organ.

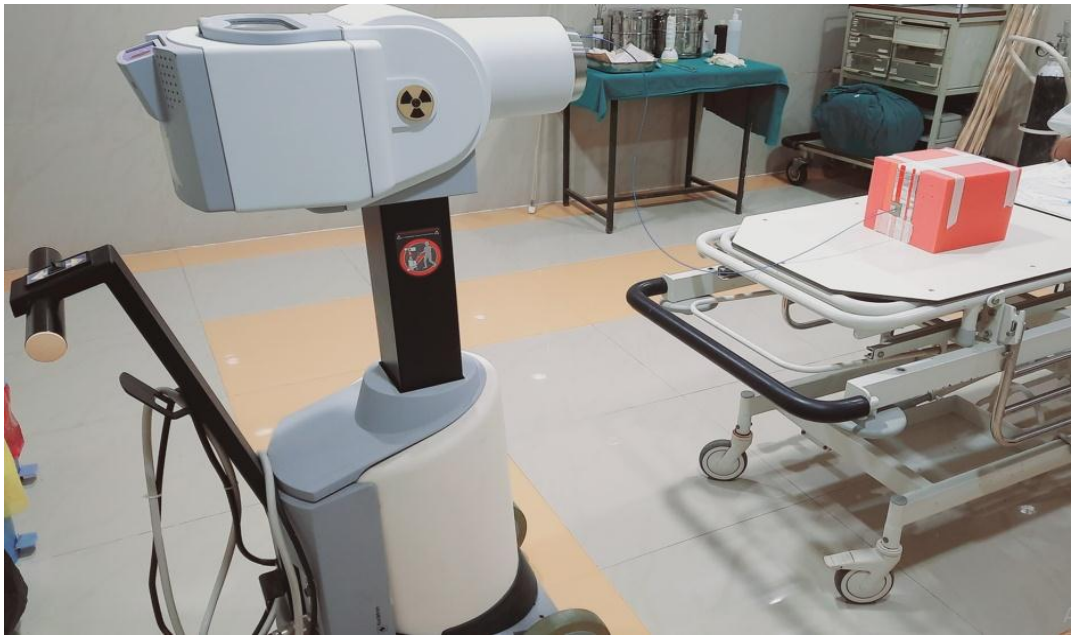


Figure 16: Showing a Phantom Connected to HDR machine for irradiation

Labeled each irradiated film very carefully. The films were stored for 48 hours in safe area for its self development and then proceed for scanning of the films in the EPSON 11000XL Flat bed scanner.

3.2.4 FILM SCANNING FOR DOSE MEASUREMENT:

The irradiated films were scanned in the EPSON 11000XL flat bed scanner after 48 hours time period post irradiation. The scanned EBT3 films were analyzed in the Image-J software for obtaining the pixel value followed by the Mean Optical

Density (MOD) (Figure 17). The images were digitized and their pixel values along the longitudinal and transverse bisector of the film were obtained. The optical density at points was calculated by using the pixel value of the point and mean background pixel value. Optical densities found in each case were further converted into absorbed doses by using the calibration curve fit equation. This equation is second order polynomial and best fit between the delivered doses and respective obtained MOD (Eq. 2). The film calibration curve and fit equation was used to calculate the doses measured by the films in the phantom post irradiation[8]. The dose at the center of each surface of the OAR was obtained by averaging the doses at five pixels around the center points. The final values of the dose were taken from an average of five measurements at the point.

Figure 17: Showing the scan images of irradiated EBT3 films at different locations in the phantom.

4. "DOSIMETRIC & VOLUMETRIC ANALYSIS" IN EBBT:

The patients of carcinoma lung were included and divided in two groups with left and right lung tumor lesion in this study. We looked into the past five years of our Hospital based prevalence of brachytherapy in lung cancer and took up thirty patients for the study period. Purposive and convenient sampling was done due to limitation of the patients. Total thirty patients [N=30] of carcinoma lung were equally distributed in two groups for left and right lung carcinoma. The two groups were further divided in two sub-groups in each main group for tumor location in lower and middle bronchus region where again almost equal numbers of patients were included. In the sub-group eight patients were lower bronchus lesion and seven patients were middle bronchus lesion in either side of the lung carcinoma. As per the target volume, thirty patients with different target volume were classified in two group TV <22cc and TV >22cc.

4.1 CATHETER INSERTION AND IMAGE AQUISITION:

Bronchoscopy was performed prior to EBBT to evaluate the tumor location, size and obstruction under the local anesthesia. The bronchoscopic findings were used to determine the target volume. The upper and lower margin of the target volume was taken very carefully. In a completely obstructive lesion, the distal margin through endoscopy was not possible to define. The Lumencare 6 French (6F) catheter was inserted through the brush channel of bronchoscope into the tumor.

Figure 18: Showing a source position simulator tool at the time of CT scan

A dummy source x-ray marker (Figure 19) was positioned in the catheter which was inserted into the bronchus to visualize the catheter in the CT images. A source position simulator instrument tool (Figure 18) was used to determine the length of the catheter and check any obstruction in the catheter prior to the CT scan[63]. The study was based on the CT scan data of the patient so there were no premedication/ anesthetic procedures required.

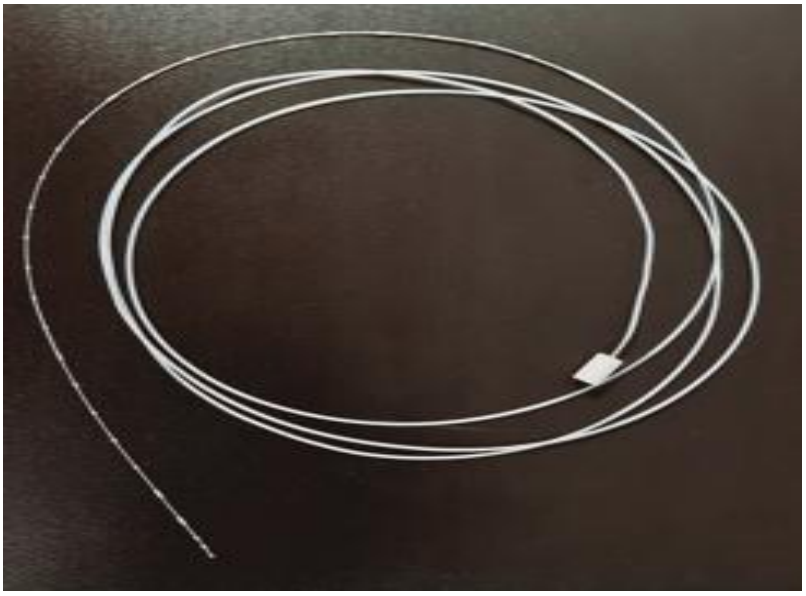


Figure 19: showing a Dummy source cable used at the time of CT scan

4.2 TREATMENT PLANNING & EXECUTION:

CT Scan of the patient was acquired in 2-3mm slice thickness in the CT Emotion Duo (Siemens Healthcare Pvt. Ltd. Make) with dummy source into it and sent to TPS [Nucletron Pvt. Ltd. make Oncentra-Master-Plan V3.3] via "Digital Imaging and Communications in Medicine (DICOM)" local area networking system for the treatment planning. Reconstruct the catheter in TPS. Source loading was done in the catheter to cover the tumor volume and extra margin on lower and upper ends was taken abide with the ABS Guidelines for endobronchial brachytherapy. The prescribed dose was 7Gy per session and normalized at 1cm from catheter center[46].

The optimized EBBT plan (Figure 20) was sent to RAL HDR machine to carry out the treatment. Each patient received total 3 sessions of EBBT so we have 3 CT image set of every patient. Target volume and organs at risk were delineated in each CT image set of the patient and same has been done for all the patients included in the study. The dosimetric and volumetric analysis was carried out in all the patients. The total doses received by OARs in three EBBT sessions were evaluated. The effects of target volume, tumor site and location on doses to organs at risk were evaluated from the dose volume histogram tool in plan analysis window in TPS.

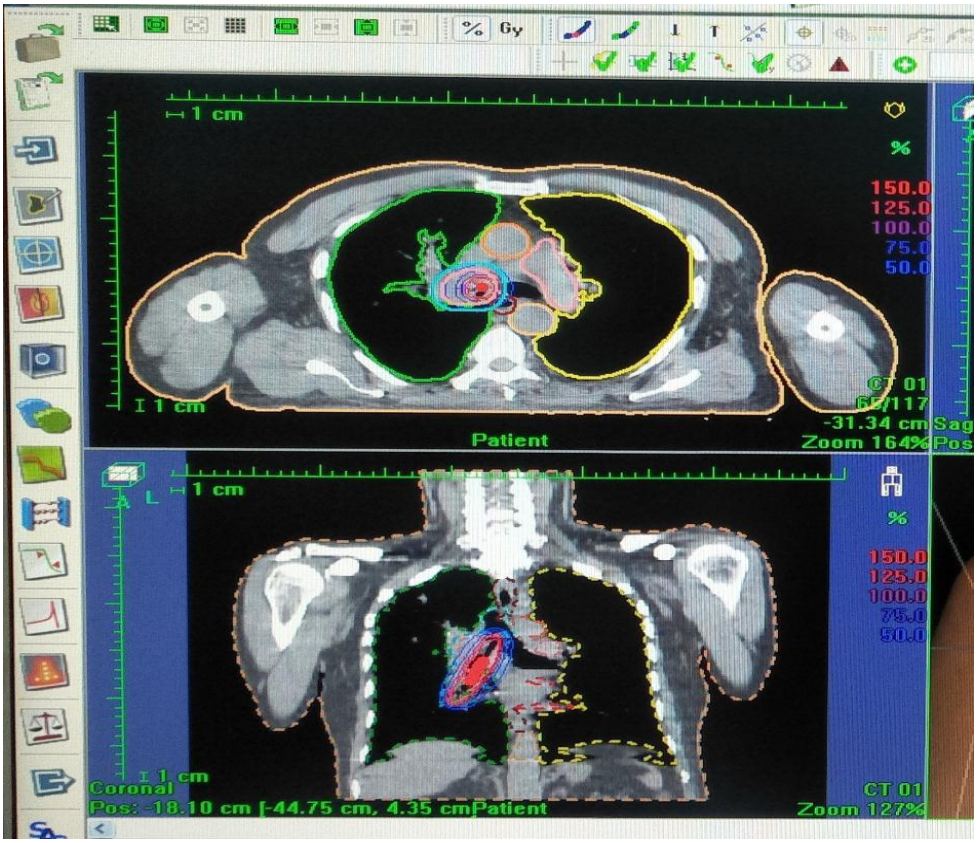


Figure 20: Showing a EBBT treatment planning of a patient with OARs and Target Volume delineated for dosimetric analysis

The tumor volume and organs at risk were delineated on CT image data set in each patient. Accurate definition of target volume and volumetric information was feasible to assess only with CT based treatment planning which improve the brachytherapy therapeutic ratio[35].

4.3 "DOSIMETRIC AND VOLUMETRIC ANALYSIS":

Dosimetric analysis was conducted on patients received Endobronchial Brachytherapy (EBBT) treatment. The doses to OARs and Effects of TV on doses to OARs were evaluated from the dose volume histogram (DVH) and detail table tool

from the plan analysis window of TPS for dosimetric and volumetric analysis of each patient after the treatment.

Volumetric variation in the target volume from first session to third session of EBBT was evaluated in the TPS.

4.4 CONFORMITY INDEX IN EBBT SESSIONS:

The target volume dose coverage was found out to calculate the conformity index (CI) in first session and third session of EBBT. Conformity Index shows the coverage of the target volume and if CI is closer to 1 than it implies that target volume is covered with the prescribed isodose in the EBBT treatment plan. CI is calculated with the following formula:

CI= Volume covered by 95% isodose/ Target volume (3)

4.5 STATISTICAL ANALYSIS:

Interpretation and analysis of the results obtained were carried out using SPSS statistics version 22 software (IBM Corp., Armonk, N.Y., USA) and MS Excel spreadsheets. The data analysis of primary objective was carried out and the two data set obtained from the experimental study was compared. The data analysis in the secondary objective was carried out and the means of organs at risk doses were compared by the parametric independent-samples t-test for the groups created for analysis purpose and it was statistically significant by $P<0.05$.