

**Analysis of 6MV Flattening Filter and Flattening Filter Free
Photon Beam in the Craniospinal Irradiation with different
Radiation Modalities**

Thesis Submitted for the Award of the Degree of

DOCTOR OF PHILOSOPHY

**In
Physics**

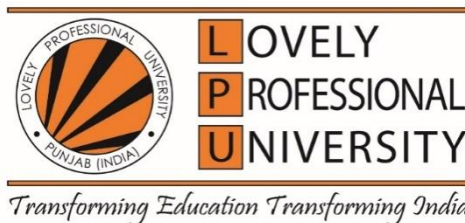
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2025

**Dedicated to my Parents
&
Family**

DECLARATION

I, hereby declare that the presented work in the thesis entitled “**Analysis of 6 MV flattening filter and flattening Filter free photon beam in the Craniospinal irradiation with different radiation modalities**” in fulfilment of my degree of **Doctor of Philosophy (Ph. D.)** is the outcome of research work carried out by me under the supervision Dr. Deepak Basandrai, working as Assistant Professor in the Department of Physics of Lovely Professional University, Punjab, India. In keeping with the general practice of reporting scientific observations, due acknowledgments have been made whenever the work described here has been based on the findings of another investigator. This work has not been submitted in part or full to any other University or Institute for the award of any degree.

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CERTIFICATE

This is to certify that the work reported in the Ph. D. thesis entitled “**Analysis of 6 MV flattening filter and flattening Filter free photon beam in the Craniospinal irradiation with different radiation modalities**” submitted in fulfilment of the requirement for the reward of degree of **Doctor of Philosophy (Ph.D.)** in the Department of Physics, is a research work carried out by Ms. Rama Devi, Reg.No:41900760, is bonafide record of his/her original work carried out under my supervision and that no part of thesis has been submitted for any other degree, diploma or equivalent course.

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ABSTRACT

Modern methods for treating cancer have advanced significantly during the past few years in all domains. Research in radiotherapy has made it possible to heal cancers that were previously believed to be incurable. Planning and delivery methods for radiotherapy have changed over time in a number of ways. Through precisely delivering radiation doses to target volumes while limiting irradiation of normal tissues, new imaging technologies, more potent computer hardware and software, and improved delivery systems have revolutionized radiotherapy and boosted patient care. These changes are deliberately developed for the benefit of cancer sufferers. Modern radiation has advanced from traditional two-dimensional (2D) planning methods that employed surface anatomy or bone landmarks to specialized planning methods that use three-dimensional (3D) computed tomography imaging to identify the target volumes and organs at risk. Planning a radiotherapy treatment is an essential step in ensuring that the tumor receives an efficient radiation dose while exposing the few healthy tissues around as little as possible. Improved outcomes with fewer side effects are now feasible due to advanced radiation procedures that have drastically improved precision. Future developments in dose reduction, enhanced imaging, and novel delivery techniques are anticipated due to ongoing research. Specialized treatment strategies that include chemotherapy and radiation therapy are essential for treating CSI with the least amount of side effects and maximum effectiveness. Goal of this study is to analyzing the quantitative and qualitative investigation of dosimetric parameters in Ca. Medulloblastoma Craniospinal Irradiation by dosimetric parameters for the tumor and vital organs are compared using 3-D radiation treatment (3DCRT) and intensity modulated radiation therapy (IMRT) approaches, Gamma Index evaluation using 2D ion matrix chambers and delivery analysis software, dose levels are measured in helical IGRT MVCT imaging with an ionization chamber and 6MV FFF and 6MV FF photon beams are used to analyze the skin entry and exit doses. According to the study's findings, sophisticated treatment planning methods including HIMRT, H3DCRT, and VMAT exhibit good target coverage for CSI. The best OAR sparing and conformal, uniform dose distribution are demonstrated by HIMRT. HIMRT can treat up to 135 cm of target length without hot and cool spot regions since it has no junctions and achieves the best V95%. When compared to H3DCRT and

VMAT, the HIMRT treatment planning approach is one of the most effective methods for CSI patients.

Helical Tomotherapy's use of delivery analysis as a component of patient-specific quality assurance is a very successful method of ensuring the precise and secure treatment of CSI patients. With MLC-LOTS, patient-specific quality assurance provides a precise, simple, and clear approach for all patient types. This is a positive and systematic approach to patient-specific quality assurance for patients with large tumors, such as those treated with helical tomotherapy after craniospinal irradiation. Making an optimal plan in terms of the essential multi-leaf collimator leaf opening time requires careful consideration of planning characteristics such as field width, pitch, and modulation factor. An optimized plan ensures patient quality assurance by providing better dosage distribution and good agreement of treatment plan delivery. The effectiveness of radiation therapy for CSI patients can be greatly increased by using this QA technique into clinical practice. CTDI_w is lowest in coarse pitch mode and highest in fine pitch mode. The patient's dose during imaging is mostly determined by the scanning area's length, pitch, and imaging site. Depending on the pitch mode and the imaging technique used for helical therapy, the patient's overall dosage may rise. Patients can receive fewer unwanted doses during imaging if they have sufficient knowledge about how to do the process accurately and without repetition. For assessing the dosages received during imaging techniques, CTDI_w is a useful technique. This work concludes the quantitative investigation of OAR volumetric doses, target volume integral doses, and skin entry exit doses. In comparison to other treatment planning techniques, statistical analysis revealed that VMAT treatment planning strategies (6MV FF) had lower skin entry-exit and integral doses. For every treatment planning method, a uniform dosage distribution was enough. The choice of treatment is determined by all dosimetric characteristics. According to the study's findings, HIMRT exhibit good treatment planning methods for CSI.

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1. **Rama Devi**, Balbir Singh, Deepak Basandrai, Craniospinal irradiation for medulloblastoma tumors: Retrospective analysis of dosimetric comparison—An institutional study, Journal of Cancer Research and Therapeutics 21(1)(2025.): 40-48 . https://doi: 10.4103/jcrt.jcrt_2305_23
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4. **Rama Devi**, Munish Kumar, Kamlesh Passi, Deepak Basandrai, Vikram Singh, Eswari V. Jayalakshmi, Delivery analysis in Tomotherapy: An efficient patient specific quality assurance (PSQA) for Craniospinal irradiation (CSI), Journal of Cancer Research and Therapeutics on 06 November 2025(Communicated).

CONFERENCE PROCEEDINGS

1. **Rama Devi**, Deepak Basandrai, Kamlesh Passi, Navneet kaur, Naveen Kanda, Ishu Sharma, Mridul Anand, Vikram Singh and Munish Kumar, Retrospective study of random and systematic errors in Head and Neck cancer Patients with Image guided Helical Intensity Modulated Radiation Therapy, RAFAS Conf., 2267,(2022) 012070. <https://doi:10.1088/1742-6596/2267/1/012070>

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LIST OF SYMBOLS

Symbol	Description
#	Fraction
%	Percentage
@	At the rate
<	Less than
=	Equal to
>	Greater than
$\leq$	Less than or equal to
$\geq$	Greater than or equal to
$D_{\max}$	Maximum dose
$D_{\min}$	Minimum dose
D_{mean}	Mean dose
Fig.	Figure
$D_{95\%}$	Dose received by 95% of the target volume
$D_{5\%}$	Dose received by 5% of the target volume
$V_{PTV\ pres}$	Volume of target covered by 95% isodose line
V_{Pre}	Total target volume receiving 100% of the prescribed dose
V_{PTV}	Total target volume
$D_{1\%}$	Dose received by 1% of the target volume
$D_{80\%}$	Dose received by 80% of the target volume
$D_{50\%}$	Dose received by 50% of the target volume
$D_{30\%}$	Dose received by 30% of the target volume
$D_{10\%}$	Dose received by 10% of the target volume
$D_{2\%}$	Dose received by 2% of the target volume
$D_{98\%}$	Dose received by 98% of the target volume
Co^{60}	Cobalt 60
M	Meter reading
N_{DW}	Absorbed dose to water calibration factor
K_{QQ0}	Beam quality factor
K_{TP}	Temperature pressure correction factor.

$V_{95\%}$	Volume receiving 95% of prescribed dose
$V_{107\%}$	Volume receiving 107% of prescribed dose

LIST OF ACRONYMS AND ABBREVIATIONS

List of Acronyms and Abbreviations	Description
2D	TWO-DIMENSIONAL
3D	THREE-DIMENSIONAL
3DCRT	THREE-DIMENSIONAL CONFORMAL RADIATION THERAPY
4D	FOUR-DIMENSIONAL
4D-CRT	4D CONFORMAL RADIOTHERAPY TREATMENT PLANNING
AAA	ANALYTICAL ANISOTROPIC ALGORITHM
AI	ARTIFICIAL INTELLIGENCE
ANOVA	ANALYSIS OF VARIANCE
ART	ADAPTIVE RADIOTHERAPY
CBCT	CONE-BEAM COMPUTED TOMOGRAPHY
CCC	COLLAPSED CONE CONVOLUTION ALGORITHM
C- DVH	CUMULATIVE DOSE VOLUME HISTOGRAM
CI	CONFORMITY INDEX
CI	CONFIDENCE INTERVAL
CN	CONFORMITY NUMBER
CNS	CENTRAL NERVOUS SYSTEM
COSI	CRITICAL ORGAN SCORING INDEX
CSF	CEREBROSPINAL FLUID
CSI	CRANIOSPINAL IRRADIATION
CT	COMPUTED TOMOGRAPHY
CTDI	COMPUTED TOMOGRAPHY DOSE INDEX
CTDI _{VOL}	VOLUME COMPUTED TOMOGRAPHY DOSE INDEX
CTDI _w	WEIGHTED COMPUTED TOMOGRAPHY

	DOSE INDEX
CTV	CLINICAL TARGET VOLUME
DD	DOSE DIFFERENCE
DDVH	DIFFERENTIAL DOSE-VOLUME HISTOGRAM
DICOM	DIGITAL IMAGING AND COMMUNICATION IN MEDICINE
DICOM RT	DIGITAL IMAGING AND COMMUNICATION IN MEDICINE IN RADIOTHERAPY
DLP	DOSE LENGTH PRODUCT
DTA	DISTANCE TO AGREEMENT (
DVH	DOSE-VOLUME HISTOGRAM
EBRT	EXTERNAL BEAM RADIATION THERAPY
EPIDS	ELECTRONIC PORTAL IMAGING DEVICES
F- IMRT	FORWARD INTENSITY-MODULATED RADIATION THERAPY
GPUS	GRAPHICS PROCESSING UNITS
GTV	GROSS TUMOR VOLUME
H3DCRT	HELICAL THREE- DIMENSIONAL RADIATION THERAPY
HDR	HIGH- DOSE RATE
HI	HOMOGENEITY INDEX
HIMRT	HELICAL INTENSITY MODULATED RADIATION THERAPY
I- IMRT	INVERSE INTENSITY-MODULATED RADIATION THERAPY
ICRU	INTERNATIONAL COMMISSION ON RADIATION UNITS AND MEASUREMENTS
ID	INTEGRAL DOSES
IGRT	IMAGE-GUIDED RADIOTHERAPY

IMRT	INTENSITY-MODULATED RADIOTHERAPY
ITV	INTERNAL TARGET VOLUME
KV	KILOVOLTAGE
LDR	LOW- DOSE RATE
LINAC	LINEAR ACCELERATOR
LOT	LEAF OPEN TIME
LOTS	LEAF OPEN TIME SINOGRAMS
MHI	MODIFIED DOSE HOMOGENEITY INDEX
MLC	MULTILEAF COLLIMATOR
MRI	MAGNETIC RESONANCE IMAGING
MU	MONITOR UNITS
MV	MEGAVOLTAGE
MVCT	MEGA VOLTAGE COMPUTED TOMOGRAPHY
NTCP	NORMAL TISSUE COMPLICATION PRABABILITY
OAR	ORGANS AT RISK
PBC	PENCIL BEAM CONVOLUTION ALGORITHM
PBT	PROTON BEAM THERAPY
PET	POSITRON EMISSION TOMOGRAPHY
PITV	PRESCRIPTION ISODOSE TO TARGET VOLUME
PSQA	PATIENT SPECIFIC QUALITY ASSURANCE
PTV	PLANNING TARGET VOLUME
QA	QUALITY ASSURANCE
QUANTAC	QUANTITATIVE ANALYSIS OF NORMAL TISSUE EFFECTS IN THE CLINIC
RPM.	ROTATION PER MINUTE
RT	RADIOTHERAPY
RTOG	RADIATION THERAPY ONCOLOGY

	GROUP
SBRT	STEREOTACTIC BODY RADIATION THERAPY
SD	STANDARD DEVIATION
SPSS	STATISTICAL PACKAGE FOR THE SOCIAL SCIENCE
SRS	STEREOTACTIC RADIOSURGERY
SRT	STEREOTACTIC RADIOTHERAPY
TCI	TARGET COVERAGE INDEX
TCP	TUMOR CONTROL PROBABILITY
TPS	TREATMENT PLANNING SYSTEMS
TT	TREATMENT TIME
TV	TARGET VOLUME
USA	UNITED STATES OF AMERICA
USB	UNIVERSAL SERIAL BUS
VMAT	VOLUMETRIC ARC THERAPY
DNA	DEOXYRIBONUCLEIC ACID
Gy	GRAY
PD	PRESCRIBED DOSE
cGy	CENTIGRAY
FFF	FLATTENING FILTER FREE
FF	FLATTENING FILTERS
EDR2 films	EXTENDED DOSE RANG
RA	RAPID ARC
DMLC	DYNAMIC MULTILEAF COLLIMATOR
MC	MONTE CARLO
HT	HELICAL TOMOTHERAPY
HF-IMRT	FIXED BINARY JAW'S- INTENSITY- MODULATED RADIATION THERAPY
HD-IMRT	DYNAMIC JAW'S- INTENSITY-

	MODULATED RADIATION THERAPY
TD-IMRT	TOMO DIRECT- INTENSITY-MODULATED RADIATION THERAPY
BOT	BEAM ON TIME
BED	BIOLOGICAL EFFECTIVE DOSE
EQU	EQUIVALENT UNIFORM DOSAGE
TC	TARGET COVERAGE
GI	GRADIENT INDEX
OBD	ON-BOARD DETECTOR
EBT3	GAFCHORMIC EXTERNAL BEAM THEAPY FILM
TLD	THERMOLUMINESCENT DOSIMETER
DD	DOSE DIFFERENCE
DTA	DISTANCE TO AGREEMENT
AAPM	TO AMERICAN ASSOCIATION OF PHYSICIST IN MEDICINE
CC	CUBIC CENTIMETRE
MSAD	MULTIPLE SCAN AVERAGE DOSES
OCR _x	OFF CENTER RATIO IN X-DIRECTION
OCR _y	OFF CENTER RATIO IN Y-DIRECTION
PDD	PERCENTAGE DEPTH DOSE
R _t	RIGHT
MTF	MODULATION TRANSFER FACTOR
MCO	MULTI-CRITERIA OPTIMIZATION
PMMA	POLY METYL METHACRYLATE
TG	TASK GROUP
AL _{cs}	CLINIC SPECIFIC ACTION LIMIT
TL _{cs}	CLINIC SPECIFIC TOLERANCE
SD	STANDARD DEVIATION
LCR	LOCAL CONTROL RATE
OS	OVERALL SURVIVAL
EFS	EVENT-FREE SURVIVAL

CRT	CONVENTIONAL RADIOTHERAPY TECHNIQUES
KI	KAPPA INDEX
IMPT	INTENSITY MODULATED PROTON BEAM THERAPY
PSPT	PASSIVE SCATTERED PROTON BEAM THERAPY
VBS	VERTEBRAL BODY SPARING
KBM _s	KNOWLEDGE-BASED MODELS

LIST OF UNITS

CC	Centimetre Cubed
cGy	Centigray
Cm	Centimetre
cm ²	Centimetre Square
cm ³	Centimetre Cubed
Gy	Gray
L	Litter
MeV	Milli Electron Voltage
mGycm	Milligray Centimetre
Mm	Millimetre
mm ³	Millimetre Cube
Ms	Milli Second
MV	Megavoltage
°	Degree
Vs	Versus
ΔD	Dose Difference
Υ	Gamma Index

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CHAPTER-1

INTRODUCTION

1.1 Radiotherapy

It is a treatment, where cancerous cells are killed with the help of high energy radiations. Radiotherapy delivers higher dose of ionized radiation to control the tumor growth.

1.1.1 Types of Radiotherapy:

Basically, two types of techniques for radiation treatment are used i.e. internal beam radiotherapy and external beam radiotherapy, which further depends on various factors encompassing:

- Type of cancer.
- Tumor size.
- The tumor site and how close it is to sensitive normal tissues.
- The current as well as previous medical conditions, as well as patient medical history.
- Other considerations include patient age and any medical concerns patient may have.

a. **External Beam Radiotherapy (EBRT):** It is a treatment, which is carried out using a machine that directs radiation from a certain distance toward the cancer site as shown in [Fig. 1.1](#). It doesn't touch the patient's body, but it can move around the patient, releasing radiation to specific region. This is the commonly type of radiotherapy, where high-energy radiation is directed to tumor site from outside the patient body using linear accelerator (linac). The patient typically lies on a machine couch, while the machine is setup around patient to deliver precise radiation to the patient tumor site. Radiation can be delivered in fractions over several days or weeks to minimize damage to healthy tissue. The Intensity-Modulation Radiotherapy (IMRT) which is Intensity-Controlled Radiotherapy and Image-Guided Radiotherapy (IGRT) which is Image-Oriented Radiotherapy, are advanced techniques used to precisely treat the target site while sparing nearby healthy tissue[\[1\]](#).



Fig. 1.1 Photograph of advanced high energy linear accelerator available at MOH, Ludhiana.

b. Internal Beam radiation therapy (IBRT)

A radioactive source is placed inside the patient body or close proximity to the patient's body as part of internal radiation therapy, as seen in Figure 1.2. It is one kind of internal radiation treatment that makes use of radioactive source. In this, radioactive seeds type source, ribbons like, or capsules type sources are implanted in area of interest or very vicinity to tumor. Brachytherapy is a local kind of therapy that targets a certain area of the patient's body. The radiation will be released from the patient's body for only a short amount of time [2]. This treatment is commonly used for cancers of the prostate, cervix, breast, and certain head and neck cancers. Brachytherapy, further can be classified into two categories

- (1) Permanent brachytherapy:** Radioactive sources are implanted in the tumor, where they emit radiation over time.
- (2) Temporary brachytherapy:** A radioactive source is placed inside a catheter or needle and removed after a certain period of time. Two types of doses can be delivered under temporary brachytherapy
 - **High-Dose Rate (HDR):** In this, higher dose of radiation is delivered in short time period (minutes to hours).
 - **Low-Dose Rate (LDR):** In this, lower dose is delivered in longer time period (hours to days).



Figure 1.2 Photograph of high dose rate brachytherapy machine available at MOH, Ludhiana.

1.2 Aim of Radiotherapy

Radiation therapy's basic idea is to give the tumor the most doses feasible while also giving the closest, most vulnerable organs the lowest radiation. This can be achieved only through delivering accurate and precisional treatment plans of patient.

1.3 Role and Importance of Radiotherapy in Cancer Treatment

Radiotherapy plays a vital role in treatment of cancer patients. It is functioning as one of the three main approaches alongside surgery and chemotherapy. This non-invasive method uses high-energy beam of radiation to targeted area and kill cancer cells while reducing damage to nearby healthy tissues. Its importance lies in its effectiveness, flexibility, and potential to improve patient outcomes[3].

One of the main benefit of radiotherapy is its precision in targeting cancer cells. Advances like intensity-modulation therapy and image oriented radiation therapy

enable highly accurate radiation delivery to tumor sites. This precision helps reduce damage to nearby healthy tissues and enhancing quality of life for the patients [4].

It can be primary treatment to eradicate cancer, as an adjuvant therapy to remove any remaining cancer cells after surgery, or as a palliative measure to relieve symptoms in advanced stages. For example, radiation has shown excellent results in managing prostate, head neck, and cervical cancers[5].

Additionally, radiation therapy is a key element of multidisciplinary cancer treatment. It is often combined with chemotherapy in a strategy called chemoradiation, which can significantly improve survival rates for various cancers, like rectal and esophageal cancers. Radiotherapy can also be given before surgery (neoadjuvant therapy) for tumor shrinkage, making them easier to remove and enhancing the chances of a successful surgery[6].

Beyond its role in treatment, radiation therapy is also important in cancer prevention and symptom management. For patients with precancerous conditions or localized tumors, early radiation can prevent the development of invasive cancer. In advanced stages, it helps alleviate pain, reduce bleeding, and improve quality of life, providing comfort and dignity to patients in their final stages of care.

Radiation therapy uses high-energy radiation to eradicate cancer cells or prevent their multiplication. [7].On the basis of cancer's type and stage, radiation therapy may be administered on its own or in combination with other treatments such as surgery, or immunotherapy. Its main purpose is to target cancer cells, which are particularly susceptible to radiation due to their rapid rate of growth and division. By damaging the DNA within cells, radiation therapy interferes with their ability to reproduce[8]. While healthy cells can typically repair this damage, cancer cells are less capable of recovery, resulting in their elimination. Based on the tumor's characteristics-such as type, stage, and location, radiation therapy can be delivered in various ways:

1.3.1. Curative Treatment: Radiation therapy is frequently employed with the intent of completely eliminating cancer, particularly when the tumor is confined to a specific area. Cancers like prostate cancer with early-staging or lungs cancer with non-small cell , it may serve primary treatment, aiming to eradicate the tumor entirely[9]. Additionally, radiation can be combined with surgery—either administered before

(neoadjuvant therapy) in order to shrink the size of the tumor or afterward (adjuvant therapy) to eliminate any remaining cancer cells.

1.3.2. Palliative Treatment: In advanced or metastatic cancer patients, radiation therapy is often used to manage symptoms and improve quality of life. Palliative radiation aims is to shrink tumors that cause discomfort, bleeding, or blockages, thereby relieving discomfort and improving daily activities. For instance, in cases of bone metastases, it can help reduce pain and lower the risk of fractures[10].

1.3.3. Neoadjuvant and Adjuvant Therapy: In some types of cancer, radiation therapy is administered either before surgery for reduction in the tumor size or afterwards surgery to destroy any remaining microscopic cancer cells. For example, in breast cancer, post-surgical radiation is often directed at the affected area to minimize the chances of recurrence[11].

1.3.4. Combination with Chemotherapy or Immunotherapy: Radiation therapy is frequently used alongside chemotherapy or immunotherapy to treat cancers that cannot be surgically removed. Chemotherapy, which utilize drugs to destroy cancer cells, and immunotherapy, which improve the body's immune response against tumors, can complement radiation therapy to improve treatment results, especially in cancers that have spread or are resistant to treatment with only one modality[12].

1.3.5 Role of Radiation in Non-Cancerous Conditions

Although radiation therapy is most commonly associated with cancer treatment, yet it has other applications too such as in the control of non-cancerous conditions[6] mentioned below

1.3.5.1 Benign Tumors:

Radiation therapy can be employed to treat benign tumors causing symptoms, such as meningiomas or acoustic neuromas, especially when surgery is not possible because of tumor's site or the patient's health condition[13].

1.3.5.2 Thyroid Disease: Radioactive iodine therapy is a common treatment for hyperthyroidism and specific forms of thyroid cancer. The iodine is absorbed by thyroid tissue, where it emits radiation to destroy the abnormal thyroid cells[14].

1.3.5.3 Pain Management: In certain situations, radiotherapy can be used to reduce pain from conditions like arthritis, especially in joints such as the knee or hip. Low-dose radiation helps reduce inflammation and ease chronic pain, providing a non-surgical treatment alternative[15].

1.3.5.4 Vascular Malformations: Radiotherapy has been utilized to treat vascular malformations, where abnormal blood vessels develop in areas like the brain or spinal cord. It can help reduce the size of these malformed vessels, alleviating symptoms and preventing further complications[16].

1.4 History of Radiotherapy

Radiation therapy, a cornerstone of modern cancer care, has undergone remarkable advancements over the past century, starting with the pivotal discoveries of X-rays and radioactivity[17]. Wilhelm Conrad Roentgen started his journey in 1895 when he discovered X-rays—electromagnetic waves capable of penetrating the body and producing internal images. In 1896, Henri Becquerel identified natural radioactivity, followed by Marie and Pierre Curie’s isolation of radium, a radioactive element with significant therapeutic potential[18]. These foundational discoveries paved the way for medical applications of radiation, and by the early 20th century, physicians began experimenting with radiation for treating diseases, especially cancer. The first recorded use of radiation to treat cancer occurred in 1896 when X-rays were used on a woman with a skin tumor, resulting in tumor shrinkage[19].

By the 1920s and 1930s, advancements in X-ray machine technology broadened the scope of radiation therapy, although early techniques were imprecise, often causing damage to healthy tissues. The development of the linear accelerator in the 1940s and 1950s marked a major breakthrough, with high-energy X-rays and delivery of more focused treatment to tumors[20]. These innovations significantly reduce side effects and increased treatment efficacy, specifically for tumors located deep within the body. In subsequent decades, further progress in imaging techniques like CT and MRI, enabled greater precision in tumor localization, leading to the more accurate radiation delivery methods[21].

Techniques like Conformal Radiation Therapy, Intensity-Modulation Radiotherapy (IMRT), and Stereotactic Body Radiation Therapy (SBRT) revolutionized cancer

treatment by enabling highly targeted radiation that minimizes damage to nearby normal tissues and critical organs [4]. Additionally, combining radiation with surgery, chemotherapy, and immunotherapy has improved cancer treatment outcomes[22]. Today, radiation therapy is a key component of both curative and palliative care for various cancers. Ongoing advancements in precision medicine and innovations in radioactive isotopes continue to drive progress in the field, offering new treatment possibilities and hope for patients with complex or advanced cancers[23].

1.5 Radiotherapy Treatment Planning and Advance Techniques

In recent years, there has been significant improvement in modern techniques in all areas of cancer treatment. Advances in radiotherapy research have allowed malignancies that were previously thought to be incurable to be cured. With the passage of time, radiotherapy planning and delivery procedures have experienced a number of changes[24]. New imaging modalities, more powerful computer hardware and software programs, and better delivery techniques have transformed the radiotherapy landscape and improved patient care by precisely delivering radiation doses to targets while limiting irradiation of normal tissues [25]. For the benefit of cancer patients, these alterations are carefully fostered. Modern radiation has progressed from conventional two-dimensional (2D) planning approaches that used bone landmarks or surface anatomy to specialized planning techniques that use three-dimensional (3D) computed tomography imaging to define the tumor regions, as well as the normal tissues and critical organs.

1.5.1 Conventional Treatment Planning: It utilizes data from 2D radiographic images of the patient's anatomical structures, with the irradiation area defined based on anatomical bony landmarks or surface anatomy. To compensate for the uncertainty in target localization, beam configurations are usually fairly simple: large fields and simple beam arrangements are used. Treatment planning and modelling were carried out in a normal field arrangement with acceptable margins, and beam ports were designed using opposing lateral fields or a three-field or four-field beam arrangement[1]. The patient's body shape was produced with plaster of Paris and traced on butter paper for treatment planning. For a number of areas, the composite dose distribution was computed manually using 2D isodose charts under the assumption of homogeneous material (water) inside the body. These isodose charts

came with the machine and were available in different field sizes. To account for the effects of contour irregularity and tissue inhomogeneity, different corrections were made to the dose distribution. The fundamental drawback of 2D-planning is that it involves irradiating a big volume as shown in Fig. 1.3, which results in a huge quantity of normal tissue irradiation, which has both acute and chronic impacts.

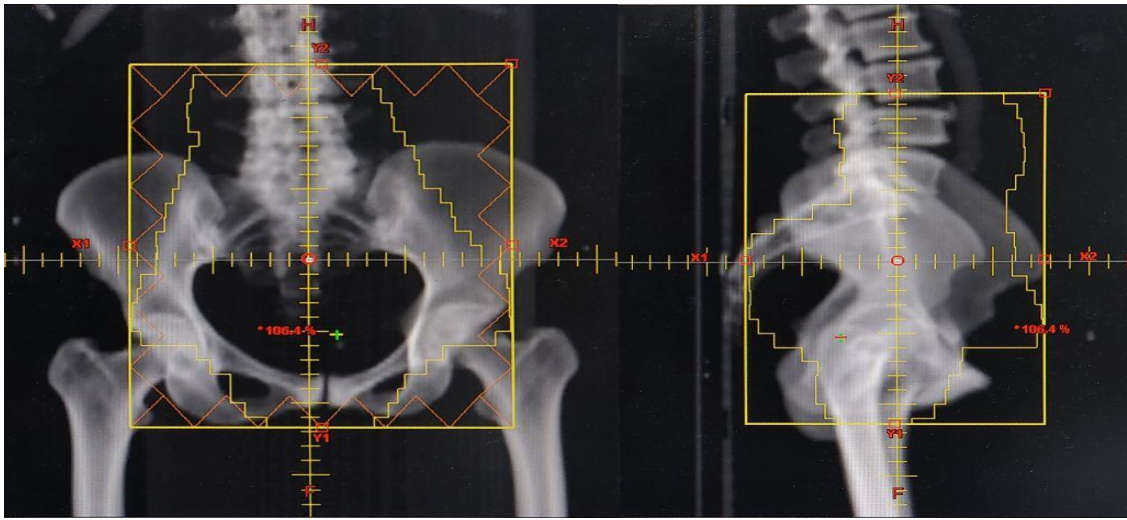


Fig. 1.3 Conventional Treatment Planning using CT simulator.

1.5.2 3D Conformal Radiotherapy (3D-CRT) Treatment Planning: Introduced in the 1990s, 3D-CRT allows clinicians to shape radiation beams to match the three-dimensional contours of a tumor. This precision ensures that tumor gets prescribed dose while sparing healthy tissues. 3D conformal planning approaches have gradually supplanted traditional planning based on 2D radiography images. This technology uses a 3D CT imaging dataset to delineate the target and OARs, then three-dimensionally conforms to the target volume using 3D-anatomic data for optimal beam placement and shielding as shown in Fig. 1.4. The multileaf collimator (MLC) is used in addition to or instead of traditional blocks and jaws. The time-consuming procedure of creating tissue compensators or blocks that conform to the goal volume has been greatly reduced since the advent of MLC. However, because MLC's lack of island blocking is still one of its primary flaws, traditional shields are still used. Wedges, dynamic jaws, and other beam modulation devices provide the beam the flexibility it needs for differential attenuation. Dose distribution is important in 3D CRT was calculated using several algorithms, each of which has its own history. Dose distribution in three dimensions that challenges patient geometry along with

influence of tissue inhomogeneity and uneven contours is taken into account by model-based algorithms such as the Pencil Beam Convolution (PBC) algorithm, analytical anisotropic algorithm (AAA), collapsed cone convolution (CCC) algorithm, and true Monte Carlo based algorithm[26]. The resultant dose distribution corresponds in close proximity to the target with this approach, delivering appropriate dose to the tumor area while delivering the lowest feasible dose to normal tissue. Consequently, clinical goals such as maximizing TCP and decreasing Normal tissue complication probability (NTCP).

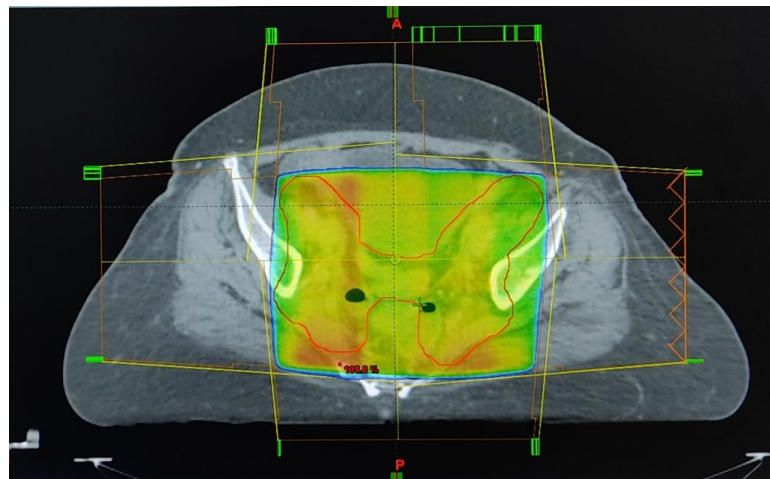


Fig. 1.4. Treatment planning for 3-Dimensional Conformal Radiotherapy based on the four-field technique

1.5.3 Intensity Modulated Radiation Therapy (IMRT): It is an advanced version of Conformal Radiation Therapy (CRT). It leverages advanced computer algorithms and linear accelerator technology which modulate the beam intensity, enabling highly targeted delivery of therapeutic doses to complex tumor shapes while reduction of exposure to adjacent normal tissues. It is especially effective for treating cancers located in anatomically complex regions, like head and neck, prostate, and brain tumours. Conventional 2D and 3D delivery systems entailed irradiating square or conformal fields with uniform intensity fluence across the field. MLC advancement enables motorized movement of MLC leaves throughout the beam on period (dynamic delivery) and between segments or planning control points of the entire irradiation time of the beam (step and shoot IMRT delivery). Dynamic and step-and-shoot type IMRT delivery methods achieve beam fluence modulation by varying the MLC position during radiation delivery[27]. These procedures explain the notion of

IMRT. IMRT, as the title indicates, allows us to vary the intensity of each radiation beam, allowing all field to have a wide range of high and low intensity patches[28]. As a result, the patient receives a non-uniform fluence from any given point of the therapy beam as shown in Fig. 1.5. The numbers of techniques that have been established for the optimization of dose distribution have built a long path of development. These algorithms are created in a variety of ways to handle inverse planning difficulties. Advanced TPS is necessary for IMRT planning, which disintegrates each beam into a great amount of beamlets and then optimizes the beam intensities of various fields to fulfil the required dose distribution parameters. IMRT varies from 3D-CRT in two major ways:

1. Inverse planning is used in IMRT.
2. Employs intensity-modulated beams, which can be further divided in two ways: In segmented MLC mode or dynamic MLC mode.

The beamlets and their intensities within each radiation field are precisely controlled to deliver a highly conformal dose focused on the target region while ensuring that the surrounding normal tissues receive only a minimal and acceptable dose. Despite the numerous advantages of IMRT, there is still room for advancement in the creation of complicated delivery strategies. Because of the many fixed gantry angle radiation beams used in IMRT, treatment delivery time is increased, which might cause patient pain, repeatability of intrafraction motion and treatment position.

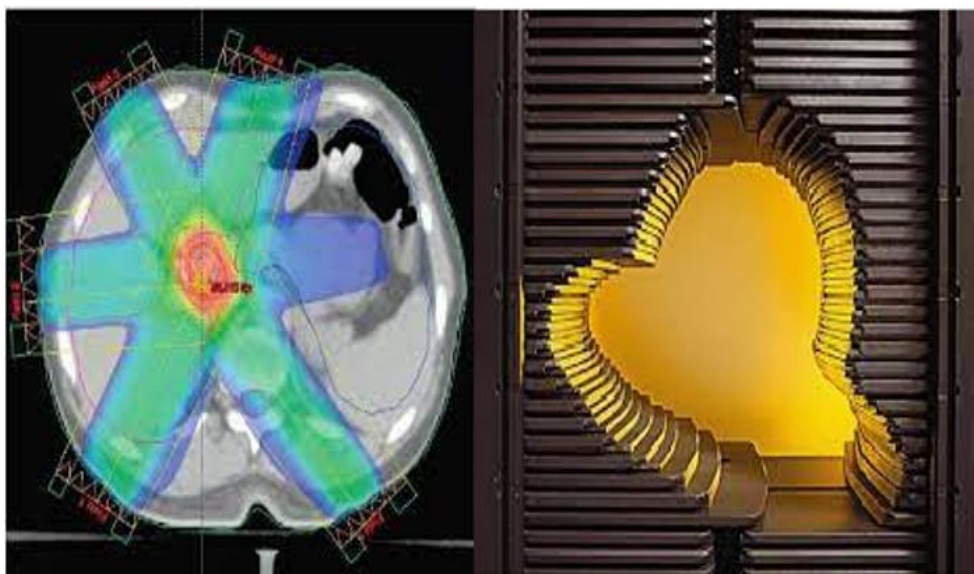


Fig. 1.5: Intensity Modulated Radiation Therapy Planning Technique using MLCs with multiple gantry angles.

Arc or rotational treatment was developed to address these issues. Yu et al. Suggested rotational IMRT delivery, which is also termed Intensity Modulated Arc Therapy[29]. Suggested rotational IMRT delivery, also known as Intensity Modulated Arc Therapy [29], involves administering radiation through continuous gantry rotation, enabling treatment from a full 360° gantry beam angle. Tomotherapy and VMAT represent the two primary types of arc-based treatment. Forward IMRT and inverse IMRT are both methods of intensity-modulated radiation therapy, but they differ significantly in how treatment plans are created:

- **Forward IMRT:** The radiation oncologist manually selects the beam angles and intensity profiles based on their clinical experience, and TPS models the resulting dose distribution
- **Inverse IMRT:** The radiation oncologist sets prescribed dose boundaries (i.e., the desired dose for the target area and surrounding normal cell), and the planning software automatically calculates the optimal beam angles, intensities, and other parameters to meet these constraints. This approach is more automated and often results in a more optimized plan, especially for complex cases[1].

While inverse IMRT is the more commonly used approach due to its efficiency and automatic optimization, forward IMRT can still be used in some clinical settings, particularly for simpler cases or when more direct control over beam selection is needed. In contrast to inverse IMRT, where the planning system determines the optimal beam configurations according to dose objectives, forward IMRT planning requires the radiation oncologist or planner to directly specify the beam configurations (including the fields, beam angles, and intensity). The radiation dose distribution is subsequently calculated by the system from these inputs.

Forward IMRT planning is a valuable technique for delivering radiation therapy, particularly for simpler treatment plans. However, inverse planning is generally considered the preferred approach due to its greater flexibility and ability to achieve more precise and conformal dose distributions.

1.5.4 Tomotherapy Treatment Planning: Tomotherapy is a special type of IMRT in which radiation is administered slice by slice, treating only one slice of the target at a time with a linear accelerator as shown in Fig. 1.6 [30]. A tomotherapy machine integrates a CT scanner-style ring assembly along with the functionality of Mega Voltage Computed Tomography (MVCT) and a linear accelerator that distributes radiations in a fan-shaped dispersion within itself, binary MLC makes tomotherapy delivery unique[31] [32]. Radiation is delivered in two ways:

1. Axial or serial delivery of radiation is in slice by slice.
2. Helical delivery, in which radiation in continuous motion of the couch (spiral delivery).



Fig. 1.6.Tomotherapy Treatment planning using binary MLCs available at MOH, Ludhiana

For a given beam delivery, the optimization method selects the most optimized values for pitch, field width, and modulation factor.

1.5.5 Volumetric Arc Therapy (VMAT) Treatment Planning: This technique was presented for the first time in 2007. The arc rotation speed, multileaf collimator leaf speed and radiation dose rate are all adjusted simultaneously in this technology to

deliver IMRT in an arc shape as shown in Fig. 1.7. The treatment delivery on standard linear accelerators with cone beam volumetric irradiation is an added advantage of VMAT over Tomotherapy. The beam constantly administers radiation as the gantry moves around patient, rather than confining therapy to a discrete number of gantry angles. MLCs also move bi-directionally to shape the radiation in real time, increasing PTV conformity and reducing treatment time[33] [34].

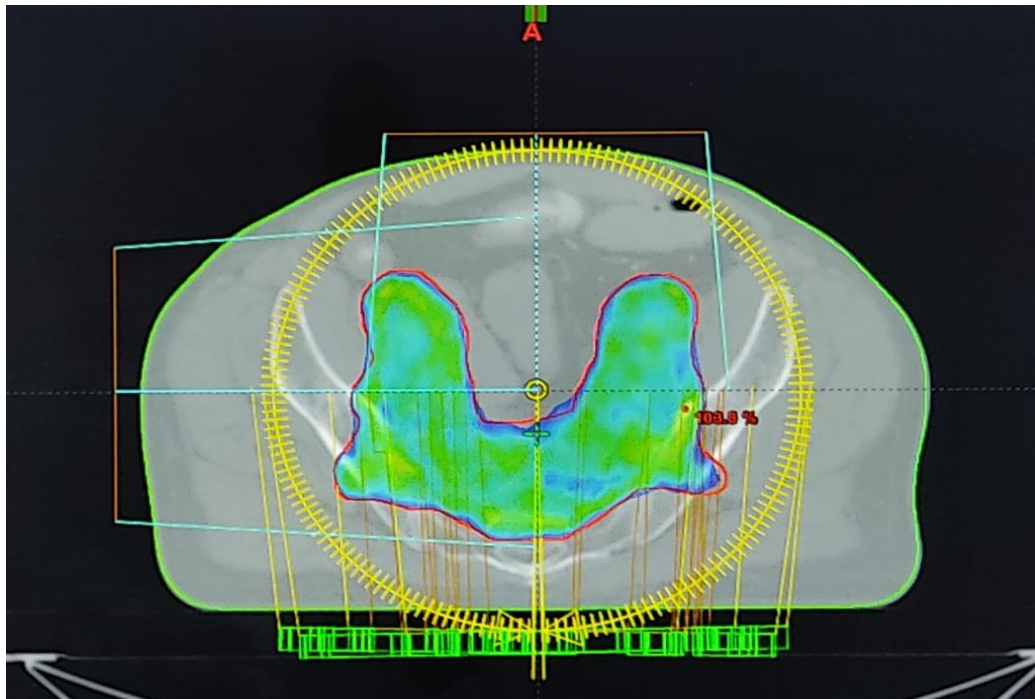


Fig. 1.7. Volumetric Modulated based Arc Therapy treatment plan

1.5.6 Image Guided Radiation Therapy planning: Before or during the course treatment, IGRT permits the use of regular imaging (2D/3D) modalities such as planar KV imaging, KV/MV cone-beam computed tomography (CBCT), and MV portal verification to ensure accurate and precise treatment delivery [1] [5]. It is feasible to identify the target during the various stages of the respiratory cycle of the patients using advanced techniques like 4D computed tomography (4D CT) as shown in Fig. 1.8. Because (i) the availability of target motion information aids in the delineation of ITV and (ii) the ITV to PTV margin is dependent on the chosen treatment method and overall system repeatability, it is possible to lower the CTV to PTV margins[4].



Fig. 1.8. Image Guided Radiation Therapy Treatment planning technique available at MOH, Ludhiana

Despite the advantages of image guidance technology, various challenges and potential limitations are there. Due to organ motion and patient setup variation, the closer margin to the treatment area and more conformal radiation delivery may have increased the likelihood of spatial miss of the intended treatment region. Despite the capacity to plan and calculate doses to sub millimetre accuracy, both the patient and the tumor may move due to voluntary movement and visceral movements such as breathing and digestion. The patient's body weight may drop throughout radiation treatment, or the tumor may shrink, altering the patient's geometry and dosimetry even further. All of these aspects provide a difficult task and are hotly debated subjects for developing more advanced approaches that can react to these changes, such as a real-time motion management system.

1.5.7 Adaptive radiotherapy (ART) and 4D conformal radiotherapy (4D-CRT)

Treatment Planning: Multiple 3DCRT data sets matching to distinct parts of the breathing cycle can now be used to record information on organ motion or anatomical changes over time, thanks to advances in CT technology. Many strategies have been developed based on this 4DCT information to help with either gating the radiation beam delivery within a threshold value or real-time synchronization of radiation beam

with the moving target as shown in Fig. 1.9. A four-dimensional (4D) planning and delivery approach has been proposed in several recent studies, in which the MLC-defined beam aperture is aligned with the beam-eye view system of the planning target volume at each phase of the respiratory cycle.[35] [36].

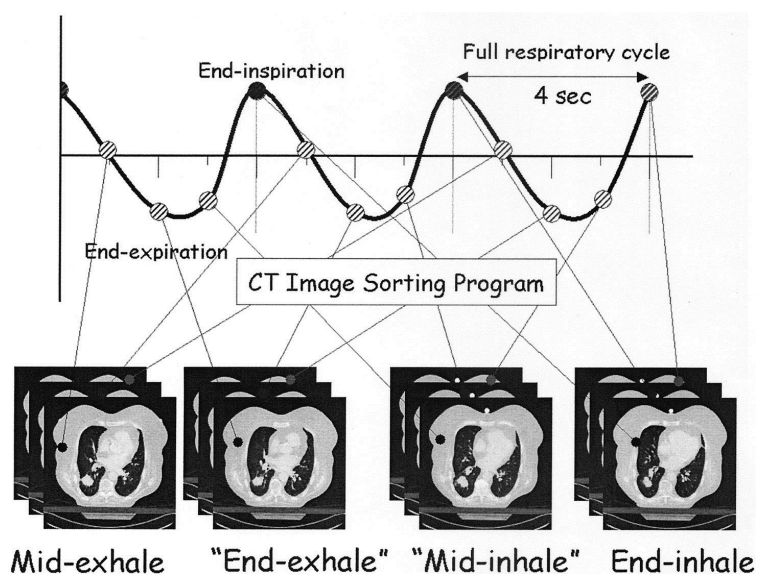


Fig. 1.9. Adaptive radiotherapy treatment planning (ART) using 4D conformal radiotherapy (4D-CRT) [37].

1.5.8 Stereotactic Radiotherapy (SRT)

Stereotactic Radiotherapy (SRT) is an advanced and precise technique for treating tumors with exceptional accuracy. It combines the principles of stereotactic imaging (for precise localization) and radiotherapy (for delivering high-dose radiation). Unlike traditional external beam radiotherapy, which typically involves delivering radiation from a variety of angles over many sessions, SRT delivers radiation from multiple precisely controlled angles in one or several treatments, often with very high accuracy[38].

1.5.9 Stereotactic Radiosurgery (SRS) is a highly advanced, non-invasive form of radiotherapy which administers a concentrated, single dose of radiation to treat tumors or other abnormalities, often in the brain or spinal cord. Despite the term "surgery," SRS does not involve any cutting or physical incision. Instead, It precisely targets the tumor with extremely focused radiation beams, providing a highly effective alternative to traditional surgical methods. SRS is one of the most precise

radiotherapy techniques available and is commonly used for small, well-defined tumors or lesions[38].

Key Features of Stereotactic Radiotherapy (SRT and SRS):

- **Precision:** SRT and SRS use sophisticated imaging and targeting technologies to focus radiation on a tumor, sparing surrounding healthy tissues as much as possible.
- **Multiple Beams:** Radiation is delivered from multiple directions, using a technique that adjusts the intensity of the beams based on the tumor's location and shape.

The linear accelerator (linac), Gamma Knife, or CyberKnife are the most common tools used to deliver the radiation:

- **Gamma Knife:** Uses gamma rays from multiple sources to focus on the tumor.
- **CyberKnife:** A robotic system that delivers highly precise radiation beams, often used for tumors in the body as well as the brain.
- **Linear Accelerator (Linac):** A type of machine commonly used in IMRT, which can also be adapted for SRS.
- **Usually Multiple Sessions:** Unlike Stereotactic Radiosurgery (SRS), which typically involves one high-dose session, SRT may involve multiple sessions (typically 3–5) over a period of time (e.g., a few days or weeks).
- **Used for Larger or Complex Tumors:** SRT and SRS is often used for larger tumors or those situated close to important structures, including brainstem or spinal cord, which might require a fractionated approach to deliver radiation safely.
- **A reduction in adverse effects:** Due its capacity to target malignancies with minimal impact to the healthy tissues around them, SRT and SRS tend to have fewer and less severe side effects than conventional radiotherapy.
- **Effective for Complex Tumors:** SRT and SRS is effective for tumors that may be irregularly shaped or located near difficult-to-avoid critical structures.
- **Potential for Higher Doses:** The precision of SRT allows for delivering high radiation doses in fewer sessions, improving the potential for tumor control.

- **Outpatient Treatment:** SRT and SRS is typically delivered on an outpatient basis, with the patient able to return home after each session

SRT and SRS: Treats body tumors (e.g., Brain, Spinal, lungs, liver, prostate, pancreatic and other metastatic tumor) primarily used for tumors that are small to medium-sized and well-defined. It is especially helpful for treating cancers that are situated in places where precision is required.

1.5.10 Stereotactic Body Radiation Therapy (SBRT):

This represents a highly advanced and precise form of radiotherapy utilized to treat cancers, located in areas of the body other than the brain or spinal cord. SBRT uses stereotactic techniques to precisely target tumors, ensuring that radiation is directly delivered to target area also less exposure to healthy tissue. Its exceptional accuracy makes it suitable for tumors that are small to medium in size and well-defined[4].

Similar to Stereotactic Radiosurgery (SRS), SBRT gives tumor large doses of radiation in a few therapy sessions (usually 1 to 5 sessions). The difference is that SBRT targets tumors within internal organs, including the lungs, liver, spine, prostate, and other soft tissues, rather than brain tumors. The difference is that SBRT is used for tumors located in areas outside the brain, including organs like the lungs, liver, spine, prostate, and other soft tissues. SBRT uses modern methods of imaging, including CT, MRI, and PET scans, to detect the tumor's precise position, ensuring that the radiation is delivered with extreme accuracy.

Benefits of Advanced Techniques

- **Increased Precision:** Advanced imaging and planning allow for sub-millimetre accuracy.
- **Reduced Side Effects:** Improved targeting spares healthy tissues, reducing acute and long-term side effects.
- **Shorter Treatment Times:** Techniques like VMAT and SBRT reduce the number of sessions required.
- **Better Outcomes:** Higher radiation doses can be safely delivered, increasing tumor control rates.

1.5.11 Proton Therapy: Proton treatment uses positively charged protons rather than X-rays, which are commonly applied in traditional radiotherapy. The ability of proton treatment to more accurately target cancers while minimizing harm to nearby healthy tissues is a clear advantage. This makes it particularly beneficial for treatment of cancers proximity to important structures like the brain, spinal cord, or eye. Proton therapy is still a relatively expensive and less widely available treatment option, but its potential for sparing healthy tissues is considerable[39][40].

The effectiveness of proton therapy's lies in the Bragg peak—a unique property of protons.

Bragg Peak: In contrast to X-ray radiation, which continues to deposit energy throughout its path, protons deliver max. of its energy at specific point known as Bragg peak as shown in the Fig. 1.10.

- This means that protons deposit minimal energy as they pass through healthy tissue, which reduces the collateral damage to normal cells.
- When protons reach the tumor, they release the majority of their energy at the tumor location, reducing adverse effects in the surrounding tissues and enhancing the therapeutic gain.

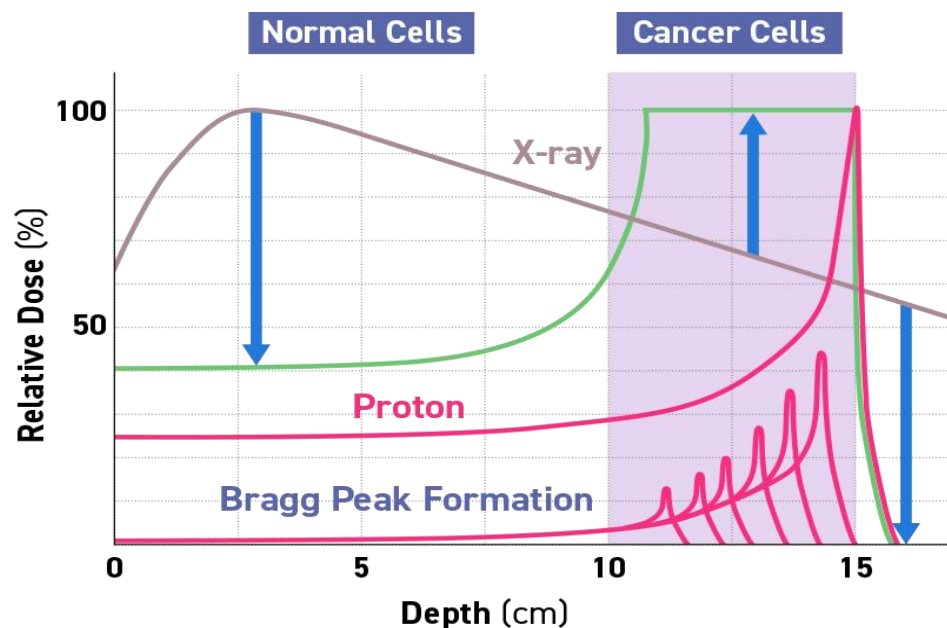


Fig. 1.10. Bragg Peak in proton therapy [41]

Proton Therapy Benefits:

- **Accuracy and Precision:** Protons deposit their energy directly at the tumor, meaning less radiation is delivered to nearby healthy tissue in contrast to traditional X-ray radiation therapy.

This is more advantageous for tumors located nearby brain, spinal cord, and lungs, where minimizing damage to normal tissue is crucial.

- **Reduced Adverse Effects:** Because proton therapy reduces radiation exposure to surrounding normal tissues, patients generally experience reduced and milder side effects compared to conventional radiation therapy. This makes proton therapy particularly beneficial for young patients, who are more radiation-sensitive, and for cancers that involve sensitive organs like the brain, eye, or spinal cord.
- **Effective for Complex Tumors:** Proton therapy is highly effective for complex, irregularly shaped tumors, where conventional radiation therapy may struggle to deliver the proper dose without harming surrounding tissue.
- **Higher Precision in Dose Delivery:** The Bragg peak enables proton therapy to precisely direct high doses of radiation at the target while protecting nearby healthy tissue. This makes proton therapy useful in cases where a high dose is necessary for tumor control but where surrounding tissue sensitivity is a concern.
- **Reduced Long-Term Risks:** Proton therapy is associated with lower risks of secondary cancers, particularly in paediatric patients, because it limits the amount of radiation scattering into healthy tissues.
- **Paediatric Use:** Proton therapy is often the preferred treatment for paediatric cancers, particularly brain tumors and other cancers in sensitive regions, because of its accuracy coupled with a reduced risk of late-onset side effects such as secondary cancers.

1.6 Basic External Beam Radiotherapy (EBRT) Work Flow:

1.6.1 Patient immobilization: Patient immobilization in radiotherapy refers to the techniques and devices used to position and stabilize patient throughout treatment process to ensure that the target area (tumor) receives an accurate and precise dose of radiation. Patient immobilization devices differ based on the target area, method of

treatment, and individual patient's needs. Below are the common types of immobilization used in different body regions:

- Head and Neck Immobilization (Thermoplastic Masks, Cradles and Headrests)
- Body Immobilization (Vacuum Cushions, Body Molds and **Positioning** devices like wedges, arm boards, or pillows)
- Pelvic Immobilization (Belly boards and Rectal Balloon)
- Breast Immobilization (Breast Boards and Breast Positioning Cushions)
- Abdominal Immobilization (Abdominal Compression and Vacuum Cushions)
- Limb Immobilization (Arm Supports and Cradles and Leg Supports)

Immobilization is crucial for ensuring reproducibility, ensuring the patient is positioned the same way for every treatment session so that the treatment plan delivered to the exact same spot every time, minimizing damage to surrounding healthy tissues[1]. Because radiotherapy often requires high precision, even small changes in patient positioning could result in the tumor receiving too much or too little radiation, potentially leading to suboptimal treatment outcomes or side effects. Therefore, immobilization techniques are used to maintain consistency in patient positioning from one treatment session to the next. The whole process of external beam radiotherapy is explained in [Fig. 1.11](#).

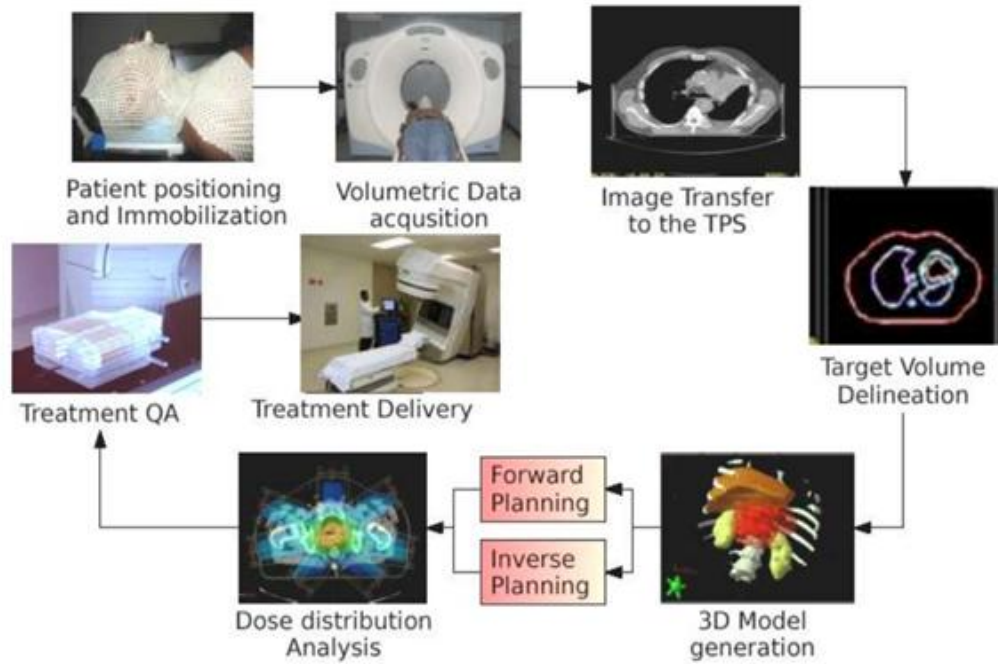


Fig. 1.11. Steps in External Beam Radiation Treatment [42]

1.6.2 Imaging and Data Acquisition: Patient imaging for simulation is an important part of the radiotherapy process. Detailed, three-dimensional (3D) scans of the patient's body are generated using advanced imaging technologies. These pictures are utilized to determine exact dimensions, size, and location of the tumor (target), along with locating adjacent normal tissues (OARs). The procedure ensures accurate planning and delivery of radiation treatment, maximizing its effectiveness while minimizing harm to surrounding healthy tissues.

1.6.3 Imaging Modalities Used in Radiotherapy: Imaging and Data Acquisition: Patient imaging for simulation is very important part of the radiotherapy process. By using new imaging technologies to create detailed, three-dimensional (3D) representations of the patient's anatomy. It utilizes advanced imaging methods to generate detailed three-dimensional (3D) models of the patient's anatomical structures. These scans are used to define the precise shape and position of the tumor (target) and distinguish the surrounding healthy tissues (organs at risk, OARs). This process ensures accurate planning and delivery of radiation treatment, maximizing its effectiveness while lesser harm to surrounding

healthy tissues. Different imaging modalities are used during simulation, based on the place and characteristics of the target, and the need for anatomical detail and functional information.

1.6.3.1 Computed Tomography (CT): CT is primary modality imaging technique for radiotherapy simulation. Patient is positioned in the treatment position, often using immobilization devices and scanner captures cross-sectional images of the body at fine intervals, usually 1-3 mm slices. It provides high-resolution 3D anatomical information. This helps in defining the targets and normal cell structure.

1.6.3.2 Magnetic Resonance Imaging (MRI): This is supplementary Modality used alongside CT for enhanced soft tissue visualization. It is superior soft-tissue contrast compared to CT and uses non-ionizing imaging method. It is ideal for tumors in areas with complex soft tissue anatomy, such as the brain, head and neck, or pelvis and fusion with CT images enhances tumor delineation in treatment planning.

1.6.3.3 Positron Emission Tomography (PET): This is functional type of imaging method which provides metabolic and functional information about the tumor. It detects areas of high metabolic activity, often corresponding to tumor sites. It is particularly useful in cancers with unclear anatomical boundaries, such as lung cancer. PET-CT fusion combines functional and anatomical data for better target definition.

1.6.3.4 4D-CT (Four-Dimensional CT): This is Dynamic Imaging which captures motion over time, such as breathing-induced movement. It is commonly used for tumors in the thorax (e.g., lung cancer) or abdomen and helps to account respiratory motion in treatment planning.

1.6.3.5 Ultrasound; It is real-Time Imaging, used for localization during simulation or treatment (e.g., prostate cancer). It is used for guiding the placement of fiducial markers and checking real-time position of soft tissues during treatment delivery. It assists in identifying the tumor's exact position, dimensions, and form as well as in accounting for tumor motion carried on by respiratory or organ motion.

1.6.4 Delineation of Target volumes and Organs at Risk: Accurate delineation of structures is a crucial step in radiotherapy patient planning. OARs are healthy normal tissues or organs located nearby target sites which can be exposed to unintended radiation. It is critical to identify and protect these organs to minimize potential side effects. Delineating OARs accurately allows for better treatment planning and helps ensure that radiation dose constraints are met. OAR delineation typically follows the principle of sparing healthy tissue as much as possible while still delivering an effective dose to the tumor. OARs are often contoured based on standard anatomical landmarks or through software-assisted automatic segmentation. The delineation of OARs will depend on the specific tumor site and treatment area[1].

Some key OARs and their importance in different treatment areas include:

Brain and Head/Neck Cancers:

- OARs: Brain, spinal cord, eyes, optic nerves, parotid glands, larynx, mandible, and others.

Lung Cancer:

- OARs: Healthy lung tissue, heart, esophagus, spinal cord.

Prostate Cancer:

- OARs: Penile bulb, rectum, small bowel, Bladder and femoral heads (if present).

Breast Cancer:

- OARs: Heart, lungs, contralateral breast, skin, and lymph nodes.

Pelvic Cancers (e.g., Cervical, Rectal):

- OARs: Bladder, rectum, small bowel, femoral heads, ovaries (in women).

In order to suppress the dose to healthy normal tissues and essential surrounding organs (OARs) while ensuring that the tumor (target) receives the recommended dosage, proper delineation can minimize adverse effects and enhance treatment results[43]. The target volume refers to the area that needs to be irradiated to treat the tumor effectively. It is defined depending on diagnostic tests (like CT, MRI, and PET)

and anatomical landmarks. Accurate delineation of the target volume is critical to ensure that the target area receives a sufficient dose to tumor while protecting surrounding normal organs. The tumour volume is usually divided into the following sub-volumes and shown in Fig. 1.12.

1.6.4.1. Gross Tumor Volume (GTV): GTV defines the tumor’s measurable or visible area identified through diagnostic imaging methods like CT, MRI, PET scan. It includes all the areas that are known to contain cancerous tissue. GTV is contoured based on the visible tumor, including primary tumor sites and any regional metastasis. The oncologist draws the GTV using imaging data that defines the tumor’s boundaries.

1.6.4.2. Clinical Target Volume (CTV): This extends beyond the GTV to encompass areas at risk of microscopic cancer spread that might not be visible on imaging. It represents the tumor area plus any regions where there is a risk of cancer involvement based on clinical knowledge. The CTV includes the GTV plus an additional margin to cover potential microscopic disease spread. The margin is influenced by the cancer type, site of treatment, and clinical indications of disease spread.

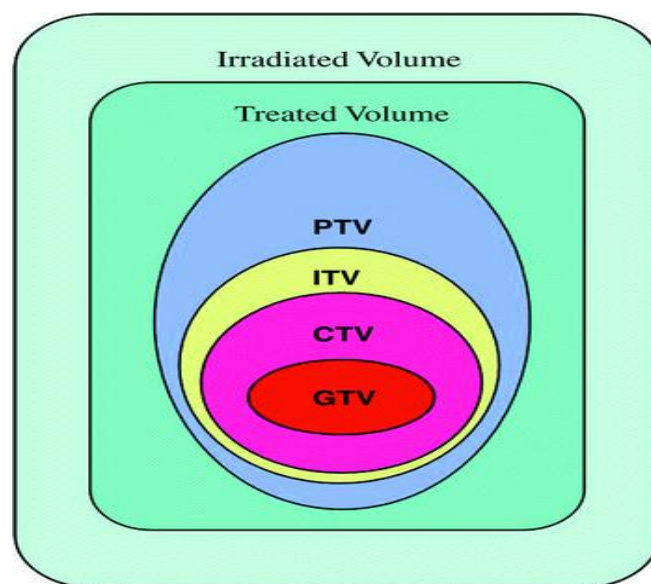


Fig. 1.12. Representation of different target volumes

1.6.4.3. Internal Target Volume (ITV): It is a critical concept in radiotherapy, particularly for tumors that are prone to movement due to respiration, peristalsis, or other physiological processes. The ITV is a target volume that accounts for tumor motion or changes in position during treatment. In simple terms, ITV is an extension

beyond the Gross Tumor Volume (GTV) that compensates due to the tumor's internal movement. This ensures the tumor receives the full prescribed dose throughout its range of motion.

1.6.4.4. Planning Target Volume (PTV): PTV represents an added margin beyond the CTV to account for changes in the tumor position, such as those caused by patient movement, organ motion (e.g., breathing or swallowing), or setup inaccuracies. The PTV is the area that should receive the prescribed dose of radiation. It considers treatment-related uncertainty in organ mobility, tumor location, and patient positioning into consideration.

1.6.5 Treatment Planning: For accurate treatment planning the following steps are followed

- **Beam Arrangement:** The Physicist determines the quantity, direction, and angles for the radiation beams that will be used.
- **Beam Shaping:** Radiation beams are adjusted to fit the target volumes, using approaches like intensity-modulation based radiation therapy and volumetric modulation based arc therapy.
- **Dose Calculation:** TPS calculates radiation energy distribution within a patient's body using beam setup and shaping.

1.6.6 Dose Calculation Algorithms

The dose calculation algorithms are crucial components of radiotherapy treatment planning systems (TPS). They mathematically represent that how the radiation interacts with the tissues of the patient to predict the dose distribution within the body. A number of different factors influence the dose calculation method selection, such as treatment technique and complexity, computational resources and Clinical needs. By employing the most appropriate dose calculation algorithms, radiation oncologists can optimize treatment plans, maximize the dosage delivery's preciseness, and ultimately enhance the outcomes for cancer patients. Here are some of the commonly used algorithms[\[44\]](#).

1.6.6.1 Pencil Beam Algorithm: This is a relatively simple algorithm that models the radiation beam as a collection of narrow pencils of radiation. It is computationally efficient and suitable for simpler treatment techniques. However, it is less accurate for advanced radiotherapy methods such as IMRT and VMAT, especially when tissue heterogeneities are present.

1.6.6.2 Convolution/Superposition Algorithm: This algorithm divides the radiation beam into smaller segments, and the dose at a point is calculated by summing the contributions from each segment. It accounts for the scattering of radiation within the tissues. It is more accurate than pencil beam algorithms, particularly for photon beams. However, it can be computationally intensive, especially for complex geometries.

1.6.6.3 Monte Carlo Algorithm: It is a statistically based algorithm that simulates individual interactions of radiation particles (photons and electrons) with the patient's tissues. It is considered the most accurate method for dose calculation, capable of handling complex geometries and material compositions. However, it is computationally very demanding, requiring significant processing time.

1.6.6.4 Analytical Anisotropic Algorithm (AAA): This algorithm combines features of both pencil beam and convolution/superposition approaches. The dose distribution around the beam's center axis is defined using analytical functions. It makes good balance within accuracy and computational efficiency. However, it does not accurately model complex treatment techniques and tissue heterogeneities.

1.6.6.5 Model-Based Algorithms: These algorithms use physical models of radiation transport to simulate the way in which radiation interacts with the tissues of the patient. They often incorporate advanced physics models and can handle complex treatment techniques and tissue heterogeneities. Its high accuracy and flexibility in modelling various treatment scenarios. However, it can be computationally demanding.

1.6.7 Plan Evaluation: Radiotherapy plan evaluation is a critical step in ensuring effective and safe cancer treatment. Through careful assessment of dose distributions, DVHs, and other quantitative metrics, we can optimize plans for

better tumor control and fewer side effects. The process involves a combination of visual inspection, quantitative analysis, and adherence to clinical guidelines. Proper evaluation leads to better patient outcomes and reduced treatment-related complications.

Michael Goitein and Verhey introduced DVHs in 1979[45]has become an important technique for evaluating radiotherapy treatment regimens in current radiation therapy. DVH is a graphical 2D histogram that summarizes 3D dose distribution data[46] [47]. Various forms of DVHs are described in the literature, but differential and cumulative DVHs are the most commonly employed. In comparison to a series of dosage intervals with same spacing, The differential DVH represents the cumulative amount of components exposed to doses within a specific dose range[45]. It directly displays the relative volume or absolute volume of each dosing interval (bin). For a target volume, one column in the DVH represents the dose delivered to the entire 100% of the target volume. OARs might display multiple peaks in their DVH, which suggests that various regions of the organ are receiving different amounts. Figure 1.13 depicts a typical DVH, with each curve indicating the dosage received by differential volume of the various outlined structures. A Dose-Volume Histogram (DVH), essential tool in radiation therapy used to evaluate how radiation is distributed within a target region (such as a tumor area) and nearby healthy tissues (organs at risk, or OARs).It gives a demonstration of how the dose is distributed across a particular area, helping clinicians ensure the treatment plan achieves the desired therapeutic goals with the goal to minimize harm to healthy tissues.

DVHs can be classified into two main types:

- **Differential DVH:** A Differential DVH shown in Fig. 1.13, is a type of graph used in radiation therapy to display the distribution of radiation doses within a given volume, such as a tumor (target) or an organ at risk (OAR). Where X-axis is dose in Gray (Gy) and Y-axis represents the absolute or relative volume of the structure that receives the corresponding dose. The dose is divided into small intervals (bins). The y-axis shows how much of the structure's volume receives a dose within each interval. The structure total volume correlates with sum of the y-axis values across all dose intervals.

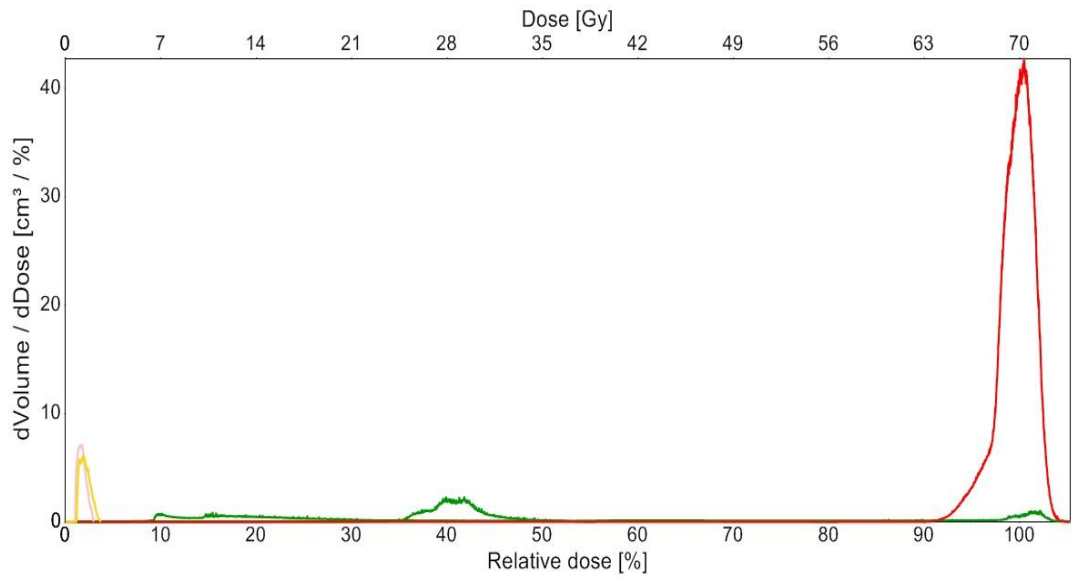


Fig. 1.13. Pictorial representation of differential dose volume histogram

- **Cumulative DVH:** A Cumulative DVH shown in Fig. 1.14, is a graphical tool used in radiotherapy to evaluate how radiation is distributed across a target volume (tumor) and nearby normal tissues. The x-axis represents the dose in Gray (Gy) and y-axis represents the cumulative percentage (or absolute volume) of the structure that gets at least that dose. The y-axis can be presented as absolute volume (in cubic centimetres or cm^3) and relative volume (percentage of the total structure's volume). A cumulative DVH always starts at 100% of the volume and decreases as the dose increases, reflecting the progressively smaller volume that receives higher doses.

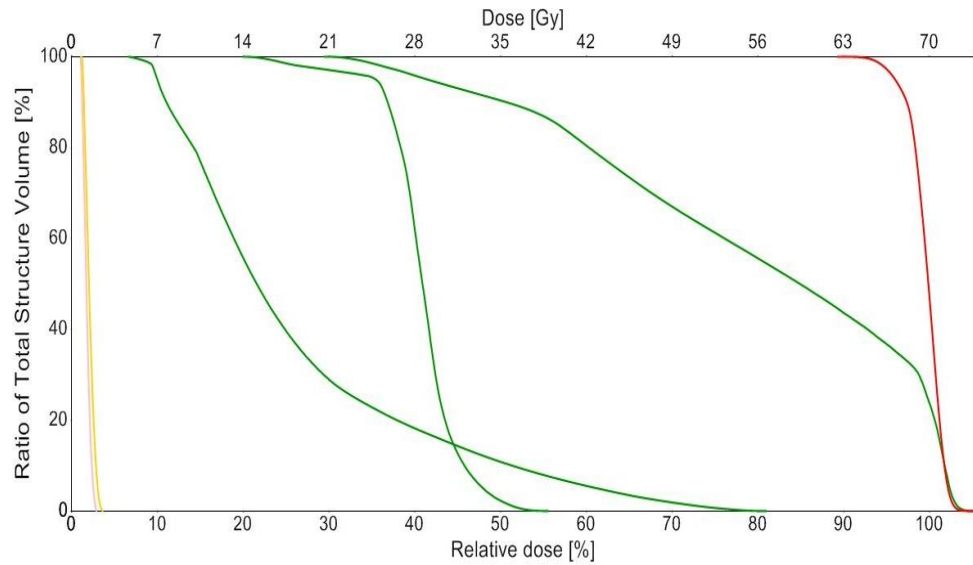


Fig. 1.14. Pictorial representation of cumulative dose volume histogram.

1.6.8 Dosimetric Analysis:

There are number of quantitative evaluation tools for plan evaluation. Max dose, mean dose, conformity number (CN), dose volume DVH, homogeneity index (HI), conformity index (CI), target coverage index (TCI), modified dose homogeneity index (MHI), quality factor (QF), and prescription isodose to target volume (PITV) ratio, critical organ scoring index (COSI) for the OAR were among them as shown in Fig. 1.15 [48].

PITV index:

The PITV index is calculated by taking the goal volume and dividing it by the stated isodose surface volume.

$$\text{PITV} = \frac{\text{PIV}}{\text{TV}} \dots \dots \dots (1.1)$$

PIV stands for prescription isodose surface volume and TV stands for target volume in the equation 1.1.

CI index:

The term CI refers to the section of a prescribed dose that is administered within the PTV. CI is written as equation 1.2.

$$CI = \frac{PTV_{PD}}{PIV} \dots\dots\dots(1.2)$$

PIV is for prescription isodose surface volume, while PTVPD stands for PTV coverage at the prescription dose in the equation above. A CI of 1 means all of a prescription dose is given to the PTV and no amount of dose is administered to any other tissue. In most clinical circumstances, the CI is smaller than one. The higher the CI value, the worse the dose conformance to the PTV.

HI index:

It is ratio of the maximum dose delivered to the PTV by the prescribed dose delivered to the PTV is known as the HI as shown in equation 1.3.

HI is written as:

$$HI = \frac{D_{max}}{PD} \dots\dots\dots(1.3)$$

PTV maximum dose is represented by Dmax in the preceding equation. The optimum homogeneous dose within a target is represented by an HI of 1. Higher HI values in the PTV suggest more dose heterogeneity.

Index	Formula	Concept	Value = 1	Value <1 or value >1
PITV (prescription isodose to target volume)	$PITV = \frac{PIV}{TV}$			
CI (conformity index)	$CI = \frac{PTV_{PD}}{PIV}$			
TCI (target coverage index)	$TCI = \frac{PTV_{PD}}{PTV}$			
CN (conformity number)	$CN = TCI \times CI = \frac{PTV_{PD}}{PTV} \times \frac{PTV_{PD}}{PIV}$			
HI (homogeneity index)	$HI = \frac{D_{max}}{PD}$			
MHI (modified homogeneity index)	$MHI = \frac{D_{95}}{D_5}$			
COSI (critical organ scoring index)	$COSI = 1 - \sum_i \frac{V_i(OAR) \geq tol}{TC}$			

Index: = PTV (planning target volume) = PIV (prescription isodose surface volume)
 = TV (target volume) = OAR

Fig. 1.15. Comparing different dosimetric indices in different clinical situations.

1.6.9. Plan Transfer:

1.6.9.1 Plan Export from Treatment Planning System (TPS):

Once the radiotherapy plan is evaluated and approved by medical physicist and radiation oncologist, it needs to be exported from the TPS. The exported data includes:

- DICOM RT files: These files contain key information about the treatment plan.

- DICOM RT Structure Set (RTSTRUCT): Defines the anatomical structures, target volumes, and OARs.
- DICOM RT Dose (RTDOSE): Contains the calculated 3D dose distribution.
- DICOM RT Plan (RTPLAN): Includes detailed machine parameters such as beam angles, field sizes, monitor units (MUs), multi-leaf collimator (MLC) positions, and gantry positions.
- The exported files are typically in DICOM RT format, which is the standard for radiotherapy data.

1.6.9.2 Plan Transfer to Treatment Delivery System

The DICOM RT files are transferred to the treatment delivery system. This can be done via:

- Network transfer: The TPS and the linac control system are often connected through a secure hospital network.
- Removable media: In some cases, files may be transferred using a USB drive or other storage media.

1.6.9.3 Plan Import and Verification:

Upon transfer, the treatment plan is imported into the treatment console. This step includes:

- **Plan import:** The linac control system reads the DICOM RT files and reconstructs the treatment plan parameters.
- **Plan verification:** The imported plan is carefully checked to ensure that no data corruption or errors occurred during transfer. Verification involves:
 - Checking that the beam parameters (e.g., gantry angle, couch angle, collimator angle, MLC position) match those in the original TPS plan.
 - Verifying dose constraints and monitor units (MUs).
 - Comparing the reconstructed dose distribution (if available) with the TPS dose distribution.

1.6.10 Quality Assurance (QA)

Before delivering of plan to patient, a QA process is performed to confirm that the treatment will be delivered accurately. This involves:

1.6.10.1 Patient-Specific QA:

The Patient specific plan is delivered to a phantom (a device that simulates the patient) while measurements are taken using detectors (e.g., ion chambers, diode arrays). The measured dose distribution is then compared with the planned dose distribution using metrics. It assists in assessing the degree of agreement between the treatment planning system's (TPS) planned radiation dose distribution and the dose distribution that the treatment machine actually delivers[49]. Modern treatment methods provide extremely complicated and conformal dose distributions, such as Volumetric Modulated based Arc Therapy and Intensity-Modulation based Therapy. Ensuring that the delivered dose matches with planned dose, is crucial for treatment accuracy and patient safety. Due to the complexity of these treatments, a simple point-by-point dose comparison may not adequately capture the overall agreement between the planned and delivered dose. In this context, Gamma Index is an important to assess spatial and dosimetric accuracy.

The Gamma Index combines two criteria for comparing the dosage distributions that were measured and planned.

Dose Difference (ΔD):

The absolute dose diff. between the TPS and actual measured dose at a given point.

Distance-to-Agreement (DTA, Δd):

The spatial distance within which the measured dose must agree with the planned dose.

1.6.10.2 Steps in Patient-Specific QA: The Patient-Specific QA using the Gamma Index involves the following steps

- **Plan Generation:** In the TPS, PSQA is created for each patient.
- **Dose Delivery:** The delivery of PSQA plan is on a phantom (a model mimicking the anatomy of patient) using the treatment machine.

- **Measurement:** The dose distribution is measured using dosimetric devices like Ion chamber arrays, Radiochromic films or Electronic portal imaging devices (EPIDs)
- **Comparison:** The Gamma Index technique is used to compare the planned distribution with the measured dose distributions.

Gamma passing criteria: -The measured Gamma index is shown in Fig. 1.16. Various gamma passing criteria mentioned below:-

- **3%/3 mm:** It is a most widely utilized criteria in clinical practice. It means that a dose difference of up to 3% and a spatial difference of up to 3 mm are acceptable.
- **2%/2 mm:** A stricter criterion used in cases requiring high precision.
- **5%/5 mm:** A more lenient criterion sometimes used for large-field or less conformal treatments.

A passing rate threshold may vary based on institutional protocols and treatment complexity.

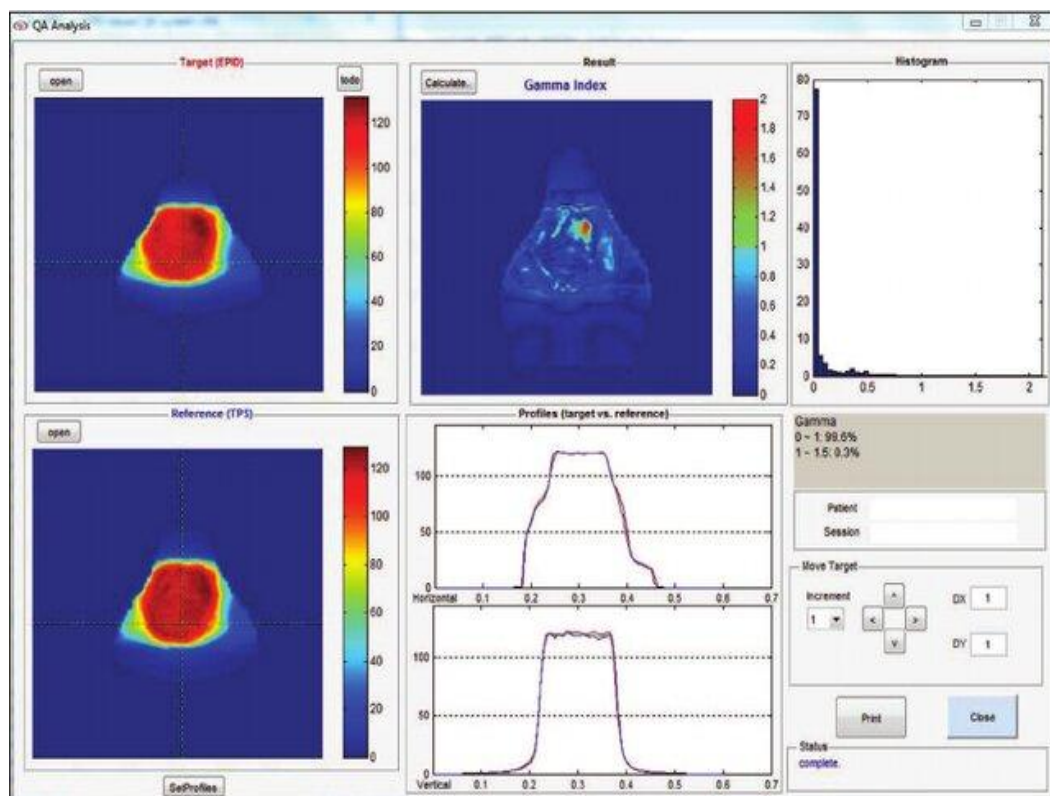


Fig. 1.16. Patient specific QA using Gamma Index for plan evaluation

1.6.11 Plan Delivery:

Once the treatment plan and machine QA are complete, the actual delivery to the patient begins.

a. Patient Positioning

- Proper positioning is crucial to ensure that the radiation beams align with the planned target.
- Immobilization devices like masks (H&N cancers) or vacuum cushions (for body treatments) are used to prevent patient movement.
- Image oriented radiation therapy is often employed:
 - Cone-beam Computed Tomography (CBCT) or kilo voltage (KV) imaging is performed before each session to confirm positioning.
 - Any necessary corrections are made before delivering the dose.

b. Radiation Beam Delivery

- The LINAC delivers the radiation beams as per the plan.
- Techniques for beam delivery include:
 - 3D- Conformal Therapy : Delivers radiation from fixed angles with shaped beams.
 - Intensity-Modulation Radiation Therapy: Modifies the radiation beams' intensity to fit with the shape of the tumor.
 - Volumetric Modulation Arc Therapy (VMAT): Delivers radiation while gantry rotates around the patient, which gives faster treatment and better dose conformity.
 - Stereotactic Radiosurgery (SRS)/Stereotactic Body Radiation Therapy (SBRT): It delivers higher amount of doses with extreme precision for small tumors.

Common Challenges in Plan Delivery:

Setup Errors:

- The tumor may be underdosed or healthy tissues may be overdosed as a result of small errors in patient positioning.
- IGRT and immobilization devices help minimize these errors.

Organ Motion:

- Internal organs may move due to breathing, digestion, or other physiological factors.
- Techniques like respiratory gating and real-time tumor tracking help address this issue.

Plan Complexity:

- Highly conformal plans (e.g., IMRT, VMAT) are complex and require rigorous QA to ensure accurate delivery.

Interfraction and Intrafraction Variability:

- Interfraction variability: Anatomically changes in the patient body during the course of treatment (e.g. weight loss, tumor shrinkage).
- Intrafraction variability: Changes in patient position or organ motion during a single session.

Mechanical QA: Ensures that the linac's mechanical components (gantry, collimator, and couch) can achieve the positions specified in the plan with high precision.

1.7 Craniospinal Irradiation (CSI): An Overview

Craniospinal irradiation (CSI) is a special radiation therapy technique used to treat entire craniospinal axis. It is most commonly used for medulloblastoma, germ cell tumors, and certain types of leukaemia or lymphoma that spread to the cerebrospinal fluid (CSF). This treatment approach is necessary because many cancers can metastasize along the CSF pathways, and CSI ensures that the entire neuraxis (brain and spinal cord) receives radiation [50].

Radiation therapy emerged as a standard cancer treatment in the mid-20th century. Initially, rudimentary techniques with low precision were used to treat brain tumors. Whole-brain irradiation was performed without specifically targeting the spinal cord, leading to high rates of relapse due to untreated spinal seeding. Advances in radiotherapy equipment and imaging, CSI as a developed unified approach to irradiate brain and the entire spinal cord. This involved using simple linear accelerators to deliver two separate radiation fields out of which one is covering the brain and upper cervical spine while the second covers the rest of the spinal cord down to the sacrum.

Improvements in planning techniques, such as two-dimensional (2D) radiographic planning, were introduced later on. However, these methods were still limited by imprecise dose delivery, resulting in cold spots (underdose) or hot spots (overdose) at junctions between the cranial and spinal fields.

1.7.1 Challenges of Traditional CSI

1.7.1.1 Field Matching: The major challenge in early CSI was achieving a seamless match between the cranial and spinal radiation fields. Misalignment at junctions often led to either underdosing (increased relapse risk) or overdosing (increased toxicity).

1.7.1.2.Toxicity : High doses of radiation to healthy tissues caused significant long-term side effects, especially in children e.g. Decline in brain function, Endocrine dysfunction, Developmental impairment, A greater probability of getting secondary cancers

1.7.2 Recent Advances in CSI Techniques

1.7.2.1. Intensity-Modulation Radiation Therapy (IMRT): IMRT precisely shapes radiation beams using advanced computer algorithms. This allows for better sparing of normal tissues and more uniform dose coverage of the brain and spinal cord[27], Reduced risk of overdose/underdose at junctions and also Improved sparing of nearby organs (thyroid, heart, lungs).

1.7.2.2. Volumetric Modulated Arc Therapy (VMAT): This is a type, in which radiation is continually administered by a rotating LINAC around the patient. This allows for more conformal dose distributions and less time of therapy[39].

1.7.2.3. Proton Beam Therapy (PBT): Proton therapy is increasingly used in CSI, especially for paediatric patients. Due to a special characteristic called the Bragg peak, protons save healthy tissues outside of the target area by confining a majority of their energy at certain depth[41].

1.7.2.4. Image-Guided Radiation Therapy (IGRT): To verify accurate patient positioning during radiation therapy, IGRT uses imaging both before and during the treatment. This minimizes errors in targeting the brain and spinal cord, reducing the likelihood of radiation misdelivery[4].

1.7.2.5 Helical Tomotherapy: Tomotherapy combines IMRT with computed tomography (CT) imaging. The machine delivers radiation in a helical (spiral) pattern, ensuring uniform coverage of large treatment areas like the brain and spinal cord[35].

1.7.2.6 Proton Arc Therapy: Proton arc therapy is an emerging approach that combines the precision of proton therapy with arc-based delivery, potentially offering better conformity and reduced treatment times[41].

Craniospinal irradiation has evolved significantly from its early days of imprecise techniques and high toxicity to advanced methods offering precise dose delivery and reduced side effects. Current techniques like IMRT, VMAT, proton therapy, and tomotherapy provide safer and more effective treatment options, especially for paediatric patients, where long-term quality of life is a major concern[50].

Ongoing research into dose reduction, improved imaging, and new delivery methods promises further advancements in the near future. Personalized treatment approaches, integrating radiotherapy with chemotherapy, hold the key to maximizing efficacy while minimizing harm in CSI treatment.

1.8 Future Directions in Radiation Therapy

The future of Radiation therapy is promising , as new developments in the field and continuing research are expected to boost its efficacy over time. The integration of machine learning and artificial intelligence (AI) is believed to have a significant effective treatment planning and optimization, helping to tailor radiation therapy to the individual characteristics of each patient's tumor. Additionally, developments in radiopharmaceuticals, which use radioactive substances for diagnostic or therapeutic purposes, are extending the use of radiation therapy to allow for more customized and targeted treatments.

Moreover, as precision medicine continues to evolve, combining radiation therapy with molecular-targeted therapies and immune therapies offers the potential for improved outcomes and fewer side effects. Advances in personalized treatment approaches, such as genetic testing and biomarker identification, will likely guide clinicians for selection of appropriate radiation treatment for individual.

Radiation therapy has played a transformative role in modern medicine, particularly in the treatment of cancer. Over the course of more than a century, it has evolved from a rudimentary technique to a highly refined, precise, and effective treatment modality. Today, radiation therapy not only plays a pivotal role in cancer care but also contributes to the treatment of a variety of other medical conditions. With continued advancements in technology, imaging, and molecular science are expected to improve effectiveness of Radiation therapy, improve quality of life and offering hope to millions of people worldwide.

1.9 The Research Study's Scope

In this research work, we attempted to analyze (i) Dosimetric difference for craniospinal irradiation patients in various treatment planning techniques like helical IMRT, Helical three 3D conformal radiation therapy and VMAT, among all the Techniques. Helical intensity modulation based Radiation therapy is the finest for craniospinal irradiation. Application of Helical IMRT in CSI patients gives better results in terms of conformity index, Homogeneity index, cold and hot spots in target area (ii) Delivery analysis software application plays very important role in performing patient specific QA for long size target volumes like craniospinal irradiation patients. Application of Delivery analysis tools for craniospinal irradiation patients gives more confidence in determination of gamma index, (iii) During Imaging procedures with MVCT computed tomography dose index is maximum in five mode through proper understanding of how MVCT can increase patient dose because of repeated imaging procedures and (iv) Patient entry, exit dose and integral doses are less in volumetric modulation arc therapy treatment planning. Helical intensity modulated radiation therapy is the best suitable for craniospinal irradiation, offering superior conformity and best treatment quality.

CHAPTER - 2

A REVIEW OF LITERATURE

2.1 Review of literature

Emami B et. al (1991): The research established one of the fundamental framework for radiation tolerance of normal tissues for the safe delivery of radiation treatment. Lungs, heart, liver, spinal cord, , kidneys, and other normal organs and tissues are among those in the authors' thorough analysis of the data currently available on radiation tolerance. Beyond which the risk of permanent damage grows, they identify thresholds and create dose-response correlations. The results highlight how TD5/5 and TD50/5 tolerances are important references in predicting radiation induced based toxicities while still providing sufficient tumor treatment in external radiotherapy. Clinicians can use the study's useful information to create radiation treatment programs that strike a balance between protecting healthy tissues and effectively controlling tumors [51].

Kapatoes J et. al. (2001) : The objective reinforced how important is patient specific dose verification in advance cancer treatment techniques. The study a new algorithm algorithm to calculate the actual dose distribution, accounting for disagreement between the planned dose and delivered doses for quality assurance. The results showed that the dose delivery could be accurately verified, with actual doses aligning well with planned doses, especially in high-dose area. The verification and dose reconstruction method was found to be feasible for clinical use and could be easily integrated into existing workflows, offering an additional layer of quality assurance for tomotherapy. This approach is valuable for ensuring safe and effective treatment delivery, particularly for complex treatments with multiple modulation levels. It was an important milestone for quality control in tomotherapy. [52].

Spezi E et al. (2005): The study investigates the quality assurance (QA) potential of a 2D ion chamber array in clinical practice by evaluating its capacity to verify dose distributions in radiation treatment. They measured dose distributions in radiation beams utilizing a 2 Dimensional ion chamber array. By comparing the measured results to calculated dose distributions and assessing the array's accuracy in measuring dose distributions in various treatment fields, the array was described. The study focused on utilizing the array to verify treatments, particularly in terms to dose

accuracy, sensitivity, and spatial resolution. The ion chamber array demonstrated minor variations from the computed doses and good accuracy in confirming dose distributions. In a variety of treatment domains, it proved useful in evaluating the dose magnitude and distribution, and it was able to identify even the smallest dose variations. Because of good spatial resolution provided by the 2D ion chamber array, small dosage variations within the treatment field may be accurately detected. Its sensitivity made it possible to calculate dose distributions in both high dose area and low dose areas [53].

Atmaram Pai Panandiker et. al (2007):In this research, the investigate potential use of IMRT for spinal irradiation, to achieve better dose distribution and reduce critical organ exposure. The results demonstrated that spinal IMRT can improve target homogeneity and optimize the dose to the spinal cord and other surrounding organs at risk. This technique allows for more precise radiation delivery, reducing the likelihood of side effects and improving clinical outcomes in patients undergoing CSI. When comparing the spinal IMRT approach to a standard PA technique, it is found that the target volume receiving $\geq 110\%$ of the given dose is reduced by 7%, while the target volume receiving $\geq 95\%$ of the prescribed dose is increased by 8%. When compared to the PA approach, spinal IMRT increased the maximum dosage administered in the paraspinal muscles by around 8.5%, despite improving target homogeneity. The study concludes that the use of spinal IMRT in craniospinal irradiation shows promising results in terms of improving treatment precision and sparing normal tissues, which may enhance long-term patient survival and quality of life [54].

Van Esch A et. al. (2007): This study demonstrated the real-time online QA technique for to ensure planned dose corresponds to the delivered dose. The QA procedure was conducted using a 3D dosimetric instrument called the Octavius phantom. The dose distribution given during treatment is measured by this phantom's 2D ion chamber array. The study find out that the QA system constructively detected small variations between TPS planned and measured dose distributions with ion chamber array providing accurate measurements, even for complex rotational treatments. The system could identify discrepancies, such as mechanical misalignments or errors in beam delivery, and detect them in real time, enabling quick corrections. The on-line QA system was found to be clinically feasible for routine use, offering a reliable method for ensuring treatment accuracy and patient safety. Real-time feedback from the

system helped prevent errors that could affect treatment outcomes. Additionally, the 2D ion chamber array was particularly effective in monitoring rotational treatments, which involve multiple angles and intricate dose distributions. The study comes to the conclusion that a reliable and accurate technique for online quality assurance of rotational radiation treatments is offered in combination Octavius phantom with 2D ion chamber array [55].

Murphy MJ et. al (2007) :The proposed study critically examined a difficult task of management of doses during imaging procedures in IGRT, specifically how to achieve an agreement between minimising patient radiation exposure while maintaining high-quality imaging. The report provides several techniques to reduce imaging doses in image-guided radiotherapy (IGRT). These include optimizing imaging protocols, adjusting exposure parameters, and implementing quality assurance measures. Routine monitoring of imaging doses and dosimetric assessments are recommended to track cumulative dose levels. To minimize imaging frequency, the use of methods like soft-tissue matching or prior imaging data is suggested, particularly for high-dose techniques like CBCT. The balance between minimizing dose and maintaining treatment accuracy is emphasized, with a recommendation to combine imaging modalities (e.g., kV imaging for setup, CBCT for verification). The author mentioned that imaging frequency as well as modality should select according to sit, complexity and motion. The study provides practitioners an extensive set of instructions for lowering imaging doses without compromising the high level of accuracy needed for image-guided radiotherapy. The work ultimately contributed to enhance the standard of radiation treatments with optimized IGRT protocols while simultaneously encouraging patient safety [56].

Mansur DB et. al. (2007): The study's main objective was to quantify peripheral radiation dosage in paediatric patients treated with conformal and IMRT procedures, with an emphasis the consequences of each approach on the nearby healthy tissue. The researchers used dosimeters in a paediatric phantom model to quantify the dose to healthy tissues beyond the treatment area (peripheral dose) for both conformal and IMRT approaches. They contrasted the peripheral dose from traditional conformal radiation therapy, which employs fixed beams with a simpler dose distribution, with that from IMRT, which shapes the dose distribution using multiple beams and sophisticated planning. When compared with traditional conformal therapy, IMRT

was found to deliver a greater peripheral dose, especially to tissues outside the central treatment region. Compared to IMRT, conformal radiation therapy produced lower doses to the surrounding healthy tissue while still providing some exposure to peripheral regions. Because of the more intricate beam arrangement, IMRT offered superior tumor targeting at the expense of high exposure to nearby healthy tissues. The study indicated the awareness regarding unplanned impact of IMRT and need for optimization techniques to reduce unnecessary exposure [57].

Buonamici FB et. al. (2007): The study's objective was to compare the feasibility, precision, and reliability of diode matrix and film dosimetry techniques for confirming the dose distribution in IMRT treatments. use a matrix of diodes for real-time dose measurement and radiographic images to quantify and assess the dosage distribution. After applying both techniques to a number of IMRT designs, the outcomes were compared to see how well they agreed with the dosage distribution that had been estimated. In IMRT QA, both the diode matrix and film dosimetry devices showed good agreement with estimated doses. Film dosimetry required more complex processing and took longer, but it was very accurate and had good spatial resolution. Despite having a lesser spatial resolution than film dosimetry, the diode matrix system was more practical for normal clinical usage since it produced findings quickly and was simpler to handle and understand. The study concluded that while both film dosimetry and diode matrix systems are useful for IMRT QA, the diode matrix system is more suited for standard clinical practice because of its effectiveness and user-friendliness [58].

Shah A et al. (2008): The study analytically evaluated the amount of radiation dose associated with MVCT imaging and its effects on patient safety, particular when it comes to its utilization for radiation treatment planning and evaluation. The authors estimated the patient dosage from MVCT imaging using computational models taking into account variables including patient size, treatment location, and imaging methods. Based on the study, patients receive a significant dosage from MVCT imaging, especially for particular procedures and treatment locations. However, compared to traditional diagnostic CT imaging, the dosages were usually lower. The anatomical region being examined, the patient's size, and imaging parameters (such as beam energy) all affected the radiation dose. Doses were increased for larger patients. In the context of radiation therapy, the dosage range from MVCT was determined to be

between 0.5 and 2.5 cGy per scan, which is significantly lower than diagnostic CT doses. The study resulted to the conclusion that despite MVCT offers useful imaging for IGRT treatment guidance, it also causes a dose that needs to be carefully controlled for the patient. The authors highlighted the significance of optimizing MVCT imaging techniques to lower patient doses while preserving the image quality essential to accurate treatment [59].

SHARMA D S et al (2009): The author analytically compared three-dimensional conformal radiotherapy (3DCRT), conventional linac IMRT and helical tomotherapy (IMRT_Tomo) in pediatric CSI patients. All patients are immobilized in the prone position with the help of head rest. Planning CT images on Somatom multislice CT scanner with 5mm slice thickness has been taken. For divergence matching of the posterior spinal field in 3DCRT Eclipse TPS employing 6 MV X-rays, blocked bilateral half beam cranial fields with collimation have been utilized. In IMRT_LA PLANNING, PTV brain and PTV spine two different plans have been created. PTV spine used five –field inverse planning tech. and bilateral beams have been used for the PTV brain In IMRT_TOMO PLANNING, 2.5 field width, and 0.3 pitch value, 3 modulation factor is used. Total 35 Gy dose is given to both PTV_brain and PTV_spine. In each of the three methods, a 95% isodose line covers the cribriform plate. However, when compared to 3DCRT and IMRT_LA, the IMRT Tomo plan delivers uniform and conformal dose distribution throughout craniospinal axis, while the 3DCRT planning shows the maximum dose heterogeneity and exit dosage along the spinal. The doses to the OAR's are less in IMRT_TOMO planning as compared to the other techniques. Tomotherapy work best for target volumes with lengthy, complex shapes and preventing junction feathering. IMRT_TOMO plans are superior in terms of target coverage, conformity, dose uniformity, OAR sparing, and reduction in integral doses [60].

Bentzen SM et al. (2010): An overview of the QUANTEC initiative, which examines the effects of radiation on normal tissues in order to develop evidence-based guidelines for safe and efficient use of radiation therapy, can be accessed in the article "Quantitative analyses of normal tissue effects in the clinic (QUANTEC): An introduction to the scientific issues" by Bentzen et al. (2010). The authors stress that

in order to inform clinical practice, measurable data regarding the correlation between radiation dose and typical tissue damage is required. The QUANTEC project aggregates data from many investigations and aims to establish dose-volume limitations for healthy tissues to lower the possibility of radiation adverse effects. Improving patient outcomes, reducing complications, and optimizing treatments all depend on this. A number of scientific difficulties in establishing dose limits and the variation in tissue reactions according to radiation type, patient characteristics, and anatomical location are also covered in the study. The article's primary point highlights how crucial it is to include quantitative data into clinical radiation therapy in order to better understand normal tissue tolerance, increase treatment planning, and ensure patient safety [61].

Yadav P, et al. (2010): The study highlighted the role of MVCT images in adaptive treatment planning as well as effect and stability of these images on adaptive TomoTherapy treatment. For patients receiving treatments with TomoTherapy, MVCT pictures were obtained. MVCT image quality was compared to planned CT image quality, specifically with regard to spatial precision and soft tissue contrast. Using the MVCT pictures, the researchers modified adaptive TomoTherapy plans and evaluated the impact on target coverage, dose distribution, and total treatment efficacy. Compared to planned CT scans, the MVCT pictures had less soft tissue contrast, but they were still considered clinically suitable for treatment guiding. There was no discernible deterioration in image quality between treatment sessions since the MVCT images remained steady over time. Treatment plans were not significantly affected by the use of MVCT for adaptive planning. Although anatomical alterations occasionally required modest adjustments, the dose distribution stayed constant and the effectiveness of the treatment wasn't significantly changed. MVCT images are a useful tool for enhancing the quality of therapy while decreasing geometric uncertainties. [62].

George Dietmar et al. (2011): The author evaluated dosimetric significance of Flattening Filter Free beams in recent advanced technologies. Flattening filter free mode is implemented for treatment in advanced radiotherapy techniques like image guided intensity modulation based radiation therapy and stereotactic radiosurgery (SRS). FFF beam has various benefits over flattened beam like high dose rate, less variation across the field size, less leakage, less treatment time and softer photon spectrum for imaging purpose. FFF have also dosimetric advantage over flattened beam like patient more comfortable, easy absorbed dose calculation, treatment planning, radiation protection, dose calculation precision and accuracy, easy treatment delivery. Flattening filters are using more than 50 years so need for long term clinical outcomes and standardization. [63].

Varatharaj Chandraraj et al. (2011) The research is based on comparison of gamma index for rapid arc and sliding window intensity modulation radiation therapy treatment techniques with PTW seven 29 detector array, Delta, IBA I'MatriXX array and EDR2 films. The PSQA has been done for 15 patients of rapid arc 10 patients of intensity modulated radiation therapy. The Varian Eclipse planning software was used to deliver treatment plans on the Varian NovalisTX linear accelerator. The pass criteria were 3mm distance to agreement with 3% of dose difference. According to passing criteria all patients, patient specific quality assurance was passed. The results shows that all the devices utilized for patient specific quality assurance gives equivalent results and dosimetric can be used for routine measurement of gamma index [64].

Pamela Myers et al. (2012) In this study gamma index has been compared for PTW 729 detector array and ScandiDos Delta detector array, who received treatment on tomotherapy machine. Sensitivity of array for 0.287, 0.433, 1.0 & 2.0 pitches has been checked. Dependence of different field widths like 1.06cm, 2.49cm & 5.02cm has been checked for all pitch values. This study includes 15 patients. Patient specific quality assurance has been done for 15 helical tomotherapy plans with PTW 729 detector array and Scandidos delta detector array. The result shows that considering 3% and 3mm passing criteria, gamma index was > 90% for all field widths and selected pitches. For patients specific quality assurance average gamma index was 97 % with delta and 97.6 % with PTW 729 detector array. This study

concludes that both devices performed with high standards and accuracy. Both devices are clinically acceptable [65].

Avanzo Michele et al. (2013): The author estimated surface dose in intensity modulation based radiation therapy, primarily focusing on radiation induced toxicity like dermatitis, alopecia and mucosa reaction. The doses to the skin are more in IMRT as compared to 3D conformal therapy (3DCRT) because of more tangential beams. Fourteen patients with cranio-spinal axis, head & neck, brain, scalp have been selected already treated with Hi-Art Helical Tomotherapy Machine. Small piece of radio chromic EBT-3 film was put to the patient's skin or inside the thermoplastic mask. Total 96 measurements have been taken for 14 patients. At the 0.05 significance level, the average diff. between the measured and TPS calculated dose is significant. The researcher found that Radio chromic EBT-3 films are accurate detectors for measurement of surface dose and improve toxicity prediction. [66].

Myser A Pamela et al (2013): The author analytically compared 3DCRT, VMAT and helical tomotherapy for five CSI patients which involved dose of 23.4 Gy divided into 13 numbers of fractions. In tomotherapy planning field width of 5.02 cm, modulation value of 2.0 and pitch used is 0.287. Smart arc planning used two isocenter in the PTV. The field junction issue is resolved by helical tomotherapy's abilities to treat continuously. Smart Arc treatment achieves modest doses to OARs and slightly greater PTV homogeneity than 3DCRT and tomotherapy regimens. The target conformance was improved by tomotherapy. Higher dosages to the surrounding organs and lowest levels of PTV conformity and homogeneity are observed in 3DCRT plans. Beam on time is slightly more in tomotherapy planning as comparison to other techniques whereas 3DCRT have shortest treatment time [67].

AL-Wassia MD Rolina et al.(2013): The author has calculated the impact of everyday MVCT imaging guidance on treatment setup accuracy and PTV in CSI patients. Twenty seven patients of CSI, median age of 21 years, 20 fractions have been selected. 5mm Computed tomography images has been taken for all patients. For every fraction setup variation systematic and random errors has been recorded on the record and verification system. PTV margin in all direction has been calculated. Daily MVCT improves the setup accuracy and reduces the PTV margin and spares critical organs. [68].

Mohammad Hussein et al. (2013): The purpose of this research is to analyse global gamma index (γ) with five different types of detector arrays. They have taken PTW 2D-array, Sun nuclear, Arc Check, Scandidas Delta4, Gafchromic EBT 2 film and Varian EPID quality assurance devices. The results shows that there is statically global agreement between predicted gamma index on virtual measurement for all softwares and detection array configuration and resolution of detector array have great effect on gamma index due to blurring effects, noise, and under-sampling of dose distribution or contribution of these effects. Conclusion of this study is that, it is very important to understand how gamma index is calculated when using different combination of detector array [69].

Phichandi Anchineyan et al(2014) The author compared advanced treatment planning techniques for CSI like FFF-IMRT and RA with 2D-CSI technique in terms of tumor coverage, homogeneity and conformity. For this study 5 patients suffering from medulloblastoma disease having median age of 10 years has been routed for CT scan and the same data has been used to generate different plans such as conventional, 6F DMLC, 6X DMLC, , 3DCRT , RA with 6X, and 6F RA with a minimum dose of 28.80 Gy. The various dosimetric parameters which includes D (max and mean), V (2%, 98%, 95% and 107%) were evaluated for different planning techniques. No significant variation has been found for D and V parameters, while 3DCRT employed minimum target dose (D_{min}) as compared to other methods. Similarly, for OAR doses other than lungs and eye shows no variation has been reported. Flattening filter free rapid arc plans gives high homogeneity and high conformity and minimum $V_{107\%}$, whereas 3DCRT gives high $V_{107\%}$. Plans with FFF beam enhances coverage, lesser beam on time, more accuracy and low doses to critical organs [70].

Handsfield L et. al(2014):The objective was to provide a phantom less QA method for TomoTherapy patient-specific verification. The technique improves the precision and effectiveness of radiation delivery verification through the use of delivery performance monitoring with an additional Monte Carlo (MC) dose computation. The authors suggested a way to monitor TomoTherapy delivery performance in real time. This involves collecting data while the treatment is actually being delivered and use it to evaluate the system's functionality. The system compares the computed dosage distribution with the planned dose distribution to ensure that the treatment is given as planned. For patient-specific QA, this approach uses MC simulations to confirm the

dosage distribution and delivery performance instead of physical phantoms. The procedure becomes quicker and more effective as a result. The study came to the conclusion that the phantomless QA method is a practical and efficient way to perform patient-specific verification. It eliminates the need for physical phantoms and increases the accuracy of dose delivery verification, which simplifies the QA process and simplifies clinical workflow [71].

Srivastava Roopam et al (2015): The author dosimetrically compared 3DCRT with Rapid arc for CSI patient. Four CSI patients have been selected, diagnosed with intracranial teratoma, anaplastic astrocytoma grade-III.. The given dose was 36 Gy in 20#. 3D CRT plans were made with collimator, couch rotation, lateral fields to the brain and posterior supine field. Junction feathering is done to ignore high dose region and low dose region at their junction region. Rapid arc plans with full arc and without any avoidance sector, with avoidance sector were made using three isocenter at the different points in PTV. The homogeneity and conformity index are good in rapid arc-based plans as compared to 3D CRT. Plans with rapid arc and avoidance sectors decreases OAR's doses as comparison to plans without avoidance sectors. A statically difference has been seen for RA + AS in comparison with 3D CRT technique for all OAR's like lungs, hearts, kidneys, liver and thyroid gland. The results shows that Rapid arc plans, especially planned with avoidance sectors gets best conformity as well as homogeneity and simultaneously low doses to surrounding critical organs. [72].

Zhang X. et al(2015): The author compared helical tomotherapy techniques for CSI patients in terms of target coverage, better homogenous dose within the target volume and simultaneously reducing the toxicity to normal organs. Helical tomotherapy (HT) has the advantage over conventional 3D CRT because HT can treat $40 \times 160 \text{ cm}^2$ target volume. 10 CSI patients have been selected, previously treated with HF-IMRT (fixed binary jaw's) same CT scan images has been used to make the different treatment plan like HT-3D CRT, HD-IMRT (dynamic jaw's) and TD-IMRT (tomo direct) with HI-ART version 4.0.4 TPS, fixed jaw size of 5cm, modulation factor is 2, pitch is 0.287, HT-3D CRT plans were made with different pitch values to evaluated the effect of different pitch. PTV (D_{mean}), D_{95} , paddic conformity index and homogeneity index has been calculated. It has been observed

that target coverage is satisfactorily in all the plans. HI and CI do not show any statistical change. Beam on time is longer for HF-IMRT as compared to other techniques. Plans with fixed jaws give more OAR doses as compared with dynamic jaws. Whole body integral dose is also almost equal in all the techniques. Plans have been with different jaw size and different pitch values. The findings concluded that dose coverage to PTV, HI, and CI is almost same in all techniques but doses to critical organs have been decreased in dynamic jaws as compared to fixed jaw position. With the increase in pitch significant improvement has been seen in target coverage, CI, HI and reduced BOT [73].

Yan Yue et al(2015): The author has calculated dosimetric and radiobiological effect of FFF beam in IMRT and Volume based modulated arc therapy. Recent advancements in the radiation therapy with Intensity modulation which includes step and shoot, helical tomotherapy, volumetric arc therapy, volumetric arc therapy (VMAT) have improved the uniform dose distribution to the target and more sparing to the critical organs as compared to 3D-conformal radiotherapy. Because of longer treatment time in IMRT gives more scatter radiation to patient and cause secondary malignancies. So, to avoid extra scatter dose, beam with flattening filter free (FFF) is the best choice. For this study thirteen patients have been selected with head and neck, lungs and prostate cancer. Static IMRT and VMAT plans generated with flattening filter (FF) and flattening filter free (FFF) beam (6 MV & 10MV). For FF and FFF beams, every parameter is the same, including beam angle, field size, arc number, and isocenter location. In addition to calculating the biological effective dose (BED) and equivalent uniform dosage (EQU), the target coverage conformity index (CI), homogeneity index (HI), target coverage (TC), and gradient index (GI) have also been computed. Histograms have been used to calculate the tumor control probability (TCP) and normal tissue complications (NTPC). The findings state that FFF indicated better target coverage, uniformity and also reduced doses to the OAR's in FFF beam [74].

Xing Aitang et al(2015): The author has estimated consistency of 3D based patient specific quality assurance with different software by evaluating gamma index. Now a days with advancements in the radiotherapy treatment planning from 3 dimensional to the radiation therapy with intensity modulated beam, arc therapy and tomotherapy, PSQA is shifting from one point calculation to the 3D dose calculation. Gamma

index is calculated from the 3D dose calculated in patient in the TPS and dose calculated in the phantom from 2D detector array. A comparison has made between two different software Verisoft from PTW and 3DVHTM from sun nuclear. Local calculation and global calculation methods has been used. Four data plans have been compared with 0mm, 1mm, 2mm, and 3mm errors keeping same slice direction resolution. The gamma passing rate has been calculated and compared with both the methods global and local. Gamma index has been calculated with Verisoft, 3DVH and manually. In all the methods gamma calculation is accurate and capable of finding any delivery errors. The author acknowledged the requirement of standardization of gamma evaluation. [75].

Minglu Liu et al. (2015); The purpose of this research is measurement of the CT Dose Index in Hi-Art Megavoltage helical Computed Tomotherapy machine. In this study we are taken CTDI_w measurements has been taken PTW TM 3009 CT pencil ion chamber in Acrylic cylindrical head and body phantoms diameter 16 and 32 cm and height is 15 cm in both phantoms for slice thickness of 2,4 and 6mm with different scanning length. The CTDI_w and DLP of Hi- Art were contrasted with KV XVI cone beam CT and brilliance simulator CT for routine scanning protocols. The result shows that slice thickness and scan length were strongly correlated with CTDI_w and DLP. Conclusion of this study, patients dose consideration for MVCT and diagnostic CT image are similar. CTDW was measured for dose reduction and QA programme in helical MVCT images [76].

Pisaturo O et. al.(2015): This investigation was done to create an effective procedure for using the on-board detector (OBD) included into the TomoTherapy system in verifying treatment plans. The authors used the on-board detector (OBD) of the TomoTherapy system to capture real-time dose distribution data during treatment delivery, allowing immediate verification of treatment accuracy. The verification procedure compared the measured dose distribution from the OBD with the planned dose distribution to ensure the delivered dose matched the treatment plan. The method was designed to be quick and efficient, minimizing the need for additional equipment or complex procedures. With measured dose distributions that nearly matched the anticipated distributions, the results showed how accurate the OBD-based verification method was. For the instances under study, this confirmed the accuracy of treatment delivery. It was an effective solution that provided a quick verification process

without requiring complicated external equipment or additional phantom measurements. The investigation came to the conclusion that the on-board detector is a useful and efficient tool for verifying the TomoTherapy treatment plan. This enhances the overall effectiveness of TomoTherapy treatments by improving the quality assurance process and providing quick and precise verification of therapy delivery [77].

Mege Jean Pierre et al(2016): The author has measured Computed tomography dose index ($CTDI_{100}$ and $CTDI_w$), at the center and periphery and focused on dose delivered during daily pre treatment verification. Image guided radiotherapy (IGRT) is a technique where imaging is done prior to the every treatment, for the improvement of radiotherapy delivery quality, accurate patient positioning and target localization. Imaging of head and neck, thorax, abdomen has been done with 3.5 MeV energy. CTDI is calculated for fine, normal and coarse mode with different pitch values. Point dose has been calculated with A1SL ion chamber with collecting volume of 0.053cm^3 and also Gafchromic films calculated the dose. LiF-type dosimeters are used for the comparison. TomoPhant (Cheese phantom) and Anthropomorphic phantoms have been used for calculation. The central and periphery doses are almost same in the ion chamber and EBT3 films. At the center of irradiation field, measured dose is 1.3 cGy for 1MVCT. To evaluate the realistic doses ATOM –CIRS phantom have been used with radiochromic EBT3 films and TLD. 4.0 cGy is the highest and 1.0 cGy is lowest calculated MVCT dose. The results show the cruciality of imaging doses in IGRT and optimized imaging protocols for adaptive kind of radiation therapy. To manage the anatomical changes in the IGRT, 2-3 sets of images can be reached, but not to go beyond 5% of prescribed dose. [78].

Hussein M. et al(2017): The author has analytically explained the effect of interpolation algorithms, number of detectors and resolution on gamma evaluation in intensity and volume arc based treatment planning. Compounded radiotherapy techniques like volumetric arc treatment and radiation therapy with intensity modulation are validated using the gamma index (γ). Because of recent advancements in the γ , now it is possible to compute the 3D dose distribution from measured 2D data from detector array. γ is sum of dose difference (DD), distance to agreement (DTA) and gives the difference between reference dose and measured

dose. γ is calculated by calculating the lowest Euclidean distance for every reference point. The passing criteria of gamma index are 3%/3mm. For comparing two 3D dose distributions, it is difficult because it is time consuming process. Spline algorithm is the best algorithm because it gives the best agreement to non-interpolated data. A comparison has been done between two different softwares OmniPro from iba dosimetry and Verisoft from PTW dosimetry. For finer grid spacing verisoft gives the better interpolation as comparison to OmniPro software. Gamma index gives quantitative analysis of measured fluence and the TPS calculated fluence. The study findings shows that difference in characteristic of QA systems and analysing tools can make dosimetric differences, so be careful during interpolation is important in case of high modulation planning techniques. [79].

Woon WuiAnn et al(2018): The author has calculated the impact of spatial resolution in gamma calculation for intensity and volume based arc therapy in patient specific quality assurance. When it comes to compounded radiotherapy techniques like as intensity modulation radiation therapy (IMRT), tomotherapy, and volumetric modulated based arc therapy (VMAT), patient-specific quality assurance (QA) is crucial in confirming the variation between the measured and estimated doses of TPS. With single chamber it is not enough to compare the dosimetric accuracy because of steep dose gradient near to the Organ at risk (OAR). Gamma index evaluation has been done using planar dose distribution. For this research five patients have been selected diagnosed with head and neck nasopharynx carcinoma. IMRT and VMAT Plans have generated for all patients with Anisotropic analytic algorithm in varian medical system using grid size of $1 \times 1 \times 1 \text{ mm}^3$. Dose 70 Gy (2 Gy per fraction) to target volume and 63 Gy (1.8 Gy per session) , 56 Gy (1.6 Gy per fraction) doses has been given to high and low risk nodes respectively. The effect of detector spatial resolution has been compared with EPID, Mapcheck, ArcCheck software on planar dose distribution. Detector spatial resolution can affect the gamma index and can give wrong results for IMRT/VMAT QA. For clinically acceptance of gamma index, every field should pass 3%/1 mm passing criteria[80].

Karaca Sibel et. Al(2018): The author has investigated the additional radiation doses during imaging in helical tomotherapy and improved setup positioning accuracy. In Helical Tomotherapy HI-Art (HT), Megavoltage computed tomography (MVCT) is used for the patient scanning before each treatment to reduce the daily

setup errors. There are three modes for imaging data acquisition coarse, normal, and fine. The disadvantage of imaging is it increases the extra doses to patient and also increase the treatment time. For his study cheese phantom with Exradin A1SL(0.057 CC) ionization chamber at different depths has been used to calculate the doses at different depths for same slice pitch. Image doses are comparatively high in head & Neck phantom relative to pelvis, abdomen and thorax region. It has been observed that doses are high at lower depth, fine pitch and oversized patients [81].

Nagata Hironori et al. (2019): The author has evaluated CTDI for MVCT imaging in helical tomotherapy by developing 3D MVCT beam model. Optimized multidirectional radiation doses has been delivered in intensity modulation radiation therapy (IMRT), using binary MLC in helical tomotherapy. Correct patient's positioning have very important role in dose delivery at tumor site. For this study five patients has been taken of different sites to determine the optimal patient position. Multiple scan average doses (MSAD) parameter is used to evaluated the MVCT doses during the tomotherapy. MVCT beam modelling has been done to calculate 3D dose distribution. Cheese phantom with Gafchromic EBT-3 films has been utilized to compute the lateral beam profile off center ratio in x-direction (OCR_x) and y-direction (OCR_y), and MVCT percentage depth dose, in order to construct an MVCT beam model. Variation in calculates and measured value is less than 2.5% for all these parameters. Right parotid is getting maximum extra doses in Head & Neck region because of anatomically thin area. Areas near to the ski surface are getting more doses. The maximum extra dose is 0.82% of prescribed dose for all organs. The study concludes that there is a small contribution of extra exposure and having relatively very small effect on total treatment doe. [82].

Marco P. De et al(2019): The author has dosimetrically analysed MVCT imaging quality as well as imaging doses during helical tomotherapy treatment delivery. Before treatment delivery, imaging has been done to rectify the positional accuracy, setup errors, inter fraction anatomically changes. Adaptive radiation therapy (ART) uses images before treatment to adapt the new treatment plan if there is any anatomical and biological change in the patient body during the treatment. For the imaging purpose 3.5MeV electron energy is used with xenon detector and filtered back projection algorithm. Image reconstruction has been done for the different pitch (fine, normal, coarse). Modulation transfer factor (MTF) has been used to access the

image quality in terms of uniformity, noise, contrast linearity, spatial resolution, contrast to noise ratio. No significant changes have been observed in the fine and normal pitches. Dose for coarse pitch has been found 1.0 cGy. The results shows that MVCT is an important tool for detection of setup errors and its important method for reducing cumulative imaging doses for IGRT treatment delivery without compromising treatment precision. [83].

Rajesh Thiyagarajan et al. (2020): The purpose of investigation is to calculate 3D dose distribution reconstructed from mega voltage CT detectors which measures leaf open time sinograms (LOTS). This study has been performed for 10 total bone marrow irradiation patients. TPS calculated doses has been compared with, doses measured with ion chamber and reconstructed doses from delivery analysis. 3D gamma index has been calculated. Results show that patient specific quality assurance with LOTS is more accurate, efficient and robust for TMT patients [84].

Goswami Brijesh et al. (2020): The integral dose (ID) inside the patient body to the large volume is because of multidirectional field technique. For this study ten patients has been selected and ID for the critical organs at risk , non-tumor target body, tumor target area has been compared for conformal radiation treatment, RapidArc, Helical Intensity modulation based radiation therapy(IMRT), Direct-3DCRTand direct IMRT modalities. 36 Gy dose in 20 fractions has been given to brain and spine target area. RapidArc is better approach for craniospinal irradiation treatment. Integral doses are less in RapidArc plans compared with Helical and Direct-IMRT. Normal tissue sparing is also better in RapidArc plans compared to 3DCRT plans [85].

Imae Toshikazu et al. (2020): The author has evaluated surface doses for 6MV FF and FFF photon beam and prediction of skin toxicity to patients after SRS and hypofractionated treatment. The importance increases in the advanced radiotherapy techniques like stereotactic radiosurgery (SRS) and hypofractionated radiation therapy because higher dose is delivered per fraction in these cases. Advance Markus Plane- Parallel chamber PTW sensitive volume 0.02 cc, solid water equivalent slabs have been used to measure the Percentage depth ionization and build up dose at different depths in phantom for Elekta Synergy 6 MV flattening filter (FF) beam and 6 MV flattening filter free beam (FFF), different field sizes ranging from 2x2 cm² 10x10 cm² have been calculated. It has been seen that dose difference is

comparatively less for all field sizes except 4.4 % variation for 2x2 cm² field size at 1mm depth. The study shows almost equal buildup doses in FFF and FF beam can use FFF beam for advance technology which required high doses per fraction. [86].

Mohandass P et. al. (2020): The research evaluated the impact of Multi-criteria Optimization on the quality of craniospinal irradiation treatment plans utilizing 6 MV FFF Volumetric modulated based arc therapy. In the study, 6 MV Flattening Filter-Free (FFF) beams were utilized for CSI treatment planning, and Multi-Criteria Optimization (MCO) was integrated into the planning process. The authors compared MCO-optimized designs with traditional planning methods. The researchers examined the dosage to critical structures, conformance index, planning parameters, and (DVH). In order to ensure that the targeted volume received enough radiation while reducing exposure to nearby tissues, MCO was used to improve the dose's conformance to the tumor. Given the sensitivity of these tissues, MCO optimization resulted in a decrease in the dosage to vital structures including the spinal cord and organs at risk, which is significant in craniospinal irradiation. According to the study, the MCO-based strategy enhanced the treatment plan's quality, particularly with regard to uniformity and reducing the dosage to healthy tissues. The study concludes that multi-criteria optimization in VMAT with 6-MV FFF beams present an effective strategy to enhancing the accuracy and security of craniospinal irradiation treatments [87].

Marco Fusella et al. (2021): The study validates the new Radixact helical tomotherapy platform with specialized Precision TPS for 395 patient-specific quality assurances (PSQA). For this research work, 395 patients have been taken treated in between June 2018 to October 2020 with different sites. 28 patients of abdomen, 32 patients of brain 77 patients of head & neck, 71 patients of lung, 84 patients of pelvis, 52 patients of prostate and 41 patients of other sites were included range of delivered dose per fraction was 1.6 – 5 Gy. For quality assurance, Arc check (Sun Nuclear, Melbourne, FL) with 15cm diameter of phantom and homogenous PMMA plugs were used 2D and 3D local and global gamma index were calculated according to AAPM TG 218 report. Various factors like Clinic specific action limit (AL_{cs}) and tolerance (TL_{cs}) were calculated. Result shows that mean global and local gamma index was 97.6% and 90.9% with ± standard deviation and AL_{cs} and TL_{cs} after two years were 89.4% and 91.1%. The conclusion of the study status that TPS calculated and measured doses were closely matched and precision of dose delivery with new

precision TPS and Radixact machine are perfect according to International standards [88].

Jennifer Novak et al. (2021): This study checked the setup accuracy in craniospinal irradiation (CSI) patients, to optimize the margins to planning target volumes. For this study 10 patients has been taken who already received CSI treatment. Setup variations have been calculated in between reference computed tomography (CT) images and daily megavoltage CT images before treatment of the patients. In antero-posterior and lateral planes, translational displacements have been measured at different positions like at sella, top L5 and top of T1 positions. Random and systematic errors have been calculated from displacement values. The minimum margin required to 90% of treatment was 6.4 mm at sella position, 8.2 mm at T1 position and 10.5 mm at L5 position. This study concludes that we ought to give 5 to 7 mm margin to brain planning target volume and 10 mm margin to spine planning target volume because there are higher setup errors in the caudal direction of the spine in the lateral plane relative to the AP plane [89].

Lee Joongyo et al. (2021): The author calculated inter and intra fractional setup error during helical tomotherapy in CSI patients. During the medulloblastoma treatment in children and adults it is very important to take care of the interfractional setup error and intrafractional movements. For this study 83 patients, average age 20.9 years, 30.6 Gy dose already treated with helical Tomotherapy has been taken. Interfractional setup errors can be calculated as difference between pretreatment imaging and planning CT scan images. Whereas intrafractional setup errors can be calculated as difference in between pre-treatment and after treatment Mega voltage computed tomography (MVCT). Maximum median interfractional setup error in antero posterior direction: 3.1mm and intrafractional displacement in all directions shows ≤ 2.3 mm has been calculated. In children intrafractional movement is because of weight loss but adults does not consider this factor. For medulloblastoma Helical Tomotherapy is accurate, precise and feasible method with acceptable setup errors. [90].

Anil Oztunali et. al (2021): The purpose of this research is to check the degree of toxicity in medulloblastoma patient after getting treatment from helical tomotherapy machine. For this study 46 patients have been taken to check the toxicity level in 27

patients treated with conventional technique and 19 patients treated with helical tomotherapy technique. They have calculated local control rate (LCR), overall survival (OS) of patient, event-free survival (EFS) of patient, acute and late radiation effects. Total median dose given was 55 Gy. After 5 years of followup event free survival was 84%. Overall survival after 5 year was 95% and after 10 years it was 84% during 99 month of follow up, 13% patient gets recurrence. In HT acute toxicity to gastrointestinal and CNS are less compared to CRT. This study concludes that when patients treated with HT, acute toxicity and chronic toxicity level are less compared to CRT [91].

Guillaume Vogin et al (2021): This study's objective was to define the cranial organs at risk (OAR) in neurooncology practice in order to optimize dose distribution and treatment planning. In this study, patient having single brain metastasis is identified and analyzed using simulation CT and MR images. Expert professionals from 16 radiotherapy centres segmented 9 OARS in brain structures, with neurooncology experts creating a unique contour set. Artview™ V 2.8.2 software was used to evaluate the following metrics: overlap ratio, Kappa index (KI), volumetric ratio, generally contoured volume, and extra contoured volume. The result shows that the mean KI for the largest OARS is good (parotid & brainstem) but for smaller OARS, KI degrades significantly (optic chiasm, cochlea). Members of the Association neuro-oncologues expression française who work as radiation oncologists did better across the board. The study's conclusion underscores the need for cerebral OAR delineation, which is a key factor in determining treatment ratio and clinical trial evaluation, as well as the variation in normal structures contouring among professionals [92].

Clemens Seidel et al (2021): Aim of this is to study evaluation of treatment techniques, current scenario and future scope of treatment in medulloblastoma patients in radiotherapy. Earlier 1990, medulloblastoma has been reviewed with combination techniques. The result shows that use of radio chemotherapy, proton treatment children with medulloblastoma. The conclusion of this study is that Radiation therapy for medulloblastoma patients is a very good type of treatment technique. But there are chances of getting late side effects, for low grade to stranded grade patient, Radiotherapy combined with chemotherapy gives curative results and reduce toxicity [93].

Joshua P. Schiff et al. (2022): This study was performed to analyse deviation, in target volumes for intermediate risk medulloblastoma receiving craniospinal irradiation (CSI). The stratified cox proportional hazards model was used to find out target deviation in terms of overall survival and event free survival. This study has been done on 461 patients. Only 32 patients showing major target deviation. Out of these, 21 patients shows target dose deviation, 4 patients showing target volume as well as target dose deviation and 7 patients showing deviation in target dose only. This study concludes that intensity modulation based radiation therapy (IMRT) considering conformity and less doses to organs at risk [94].

Biplab Sarkar et al. (2023): The research work focused to evaluate the Truebeam C arm linear accelerators, Halcyon ring gantry, and Volumetric Modulated based Arc Therapy plan for CSI patients. They have taken 25 patients in that 11 patients they planned for Halcyon linac using 6 MV unflattened photon beams and 14 patients they planned for VMAT in truebeam. For the low and intermediate risk categories, they delivered 23.4 Gy dose in 13 fractions in 13 patients, whereas in the patients with high-risk category, they delivered 35 Gy in 21 fractions or 36 Gy in 20 fractions to 12 patients. The parameters taken for according to treatment plans were DVH for Target dose, Organ at risk and monitor unit (MU). They evaluated the homogeneity indexes, conformity indexes, MU, dosage spillage, volume receiving $\geq 107\%$ dose, and dose received by 95% PTV volume in the target dose. Target parameters PTV 95 %, V107%, MU, CI its showing statistical significance with both HAL plan and TB plan both plan are significantly same. This study's conclusion, when it comes to organ dose and leakage doses, Halcyon-based plans are dosimetrically superior to Truebeam plans [95].

Nobuyoshi Fukumitsu et al. (2023): The aim of this study was compared the use of proton beams for CSI and its initial experience in treating paediatric patients. 24 patients of proton CSI using various techniques in that we have taken 13 patients for whole vertebral body and other remaining 11 patients for vertebral body sparing technique. The study examined critical organs, PTV and clinical data, with a median period of 17-44 months follow-up. The result shows that PSPT having less lens doses in contrast to IMPT and VBS technique shows less mean thyroid, lung, oesophagus and kidney doses. The conclusion of this study was for IMPT, PTV coverage is

superior to that of PSPT. VBS technique having reduced doses to the lens and neck, chest and abdominal site [96].

Willaiam G. Breen (2024): This study compared photon and proton CSI treatment for adult medulloblastoma. This is retrospective study, 39 patient treated with CSI techniques. In which, twenty patients were treated with photon beam therapy and nineteen patients were treated with proton beam therapy. Total dose of 36Gy in 20 fractions was given to brain and spinal cord with boost dose of 54-55.8 Gy. The results shows that patient treated with proton therapy received lesser doses to cochleae region, lacrimal glands, parotid glands, pharyngeal constrictors, eye, lenses, liver, and lungs. After 5 years of follow-up 5 patients treated with photon therapy were died due to progressive disease and 21% patients have major cardiovascular problems. After 10 years follow up 89% patients were alive and about 82% patients were without recurrence. This study conclude that patients treated with proton therapy have less acute toxicity and less weight loss through treatment duration. [97].

Harley K. Perlow et al. (2024): Aim of this study was to treat CSI patient using Volumetric based Arc Therapy utilizing vertebral body sparing and to minimize toxicity in adult patients and comparison to proton based CSI. They have taken 10 patients diagnosed with LMD, receiving dose of 30 Grey in 10 sessions with VMAT technique and 2 spine isocenter for upper and lower spine. For toxicity reduction of vertebral body, separate entry and exit contours was created. The result shows that out of 10 patient's one patient having grade 1 hematologic toxicity. Further they have investigated that 3 patients having grade 2 gastromtestional toxicity and other 7 patients having grade 1 nausea there was no patient with grade 3 toxicity. The conclusion of this study is that CSI patient's toxicity under tolerance when it is compared with proton therapy [98].

Julie Savagner et al. (2024): The study evaluated level of toxicities in paediatric and adult craniospinal irradiation (CSI) patients. This is the study of 79 patients which received CSI between September 2009 to January 2020. The median age of 13 years and median dose given was 36 Gy out of 79 patients, 77 patients received boost dose to primary tumor. Follow up time was 55.5 months. Event free survival rate was 66.3% for 3 years 85.9% of the patients suffered from active haematological toxicities during treatment and 39.7% patients suffered with severe thrombocytopenia. 63

patients were assessed for medium and long term toxicities. Out of these 52 patients survived but only 47 patients were diseases free. 3.8% patients got secondary malignancies like meningiomas and diffuse intrinsic pontine glioma. In both the case adult and paediatric patients got secondary cataract, hearing disorder and psycho cognitive disorders. The conclusion of this study is when CSI is delivered with helical tomotherapy, there are no acute and late toxicities when compared to CSI delivered with conformal radiation therapy [99].

Niketa Thakur et al (2024): The study evaluated dosimetric comparison of two volume modulation based arc therapy for optimizing CSI for medulloblastoma patients. We are taken 8 adult CSI patients we are creating two plans one plan is VMAT partial arc (VMAT_pa) and other plan is VMAT avoidance sectors (VMAT_as). We have been prescribed for 36Gy in 20 fractions. The result shows that PTV volume for $V_{95\%}$ VMAT_as 97.51% and 97.99% for VMAT_pa and $V_{107\%}$ VMAT_as 0.733 and 0.742 for VMAT_pa. The dose for OAR such as lens, eye, lives and gonads dose for both plans for similar. Other OAR like thyroid, kidneys and lungs are significantly lower dose for VMAT plans using avoidance sector [100].

Paolo Caricato et. al. (2025): The study evaluated efficiency and accuracy of knowledge-based models (KBMs) in the planning of paediatric patients' craniospinal irradiation. They evaluated how using KBMs can improve treatment quality, cut reduce planning time, and improve dose distributions—especially for critical paediatric tissues. In the study, KBM-based plans and conventional planning methods were compared, and factors like dose conformity, organ sparing, and overall treatment effectiveness were investigated. The findings showed that KBMs can achieve results that were on par with or better than those of traditional treatment planning techniques, especially when it came to lowering amount of doses to OARs and enhancing dose conformity in the target volume. According to the study, KBMs greatly reduced planning times, which is important in clinical practice, particularly for young patients who need quick, accurate care. The study shows remarkable benefits and less treatment planning time and elevate the quality without compromising clinical outcomes but further studies required for validation .[101].

2.2 Research Gap

Craniospinal irradiation is one of the challenged radiotherapy treatment due to its complex target geometry and long length of target area including brain to spinal cord. To achieve homogenous dose distribution while reducing doses to OARs is dosimetric as well as clinical challenge. Conventional CSI methods frequently encounter limitations like hot or cold spots at the junction area. Conventional approaches involve a high integral dose and more exposure to OARs.

Although recent techniques came to overcome limitations, but some of gaps are still presented in literature and mentioned below:

- (1) No research work exists on correlative analysis of Helical-IMRT, Helical-3DCRT and VMAT planning methods for craniospinal irradiation.
- (2) There application of Delivery analysis based patient specific quality assurance (PSQA) in craniospinal irradiation gets limited attention.
- (3) In most of the literature review sample size is very less, which can be increased to validate the planning techniques for large group of patients.
- (4) There is lack of literature review regarding skin, entry, exit doses and integral doses for craniospinal irradiation.

To acknowledge these research gaps, my current objectives focused on identifying the best treatment planning techniques, accurate patient specific quality assurance and integral doses to CSI patients. This study seeks to carry out the treatment planning techniques with best conformal dose distributions and reduced radiation to surrounding sensitive tissues which will leads to better therapeutic results.

The most accessible and therapeutically relevant advanced external beam radiation treatments for CSI are HIMRT, H3DCRT, and VMAT. The effective balance between dosimetric quality and clinical feasibility can be found by comparing all three of these techniques. The study's sample size of twenty patients is sufficient because the disease is rare and confirming the acceptability and scientific validity of such a sample set for this kind of study.

2.3 Objectives of the Study

The objectives are given below:

- Comparison of dosimetric parameters for the target and normal structures treated through intensity modulated radiation therapy (IMRT) and 3-D radiation therapy (3DCRT) techniques
- Evaluation of Gamma Index with Delivery Analysis Software and 2D ion matrix chambers.
- Measurement of dose levels in helical IGRT MVCT imaging with ionization chamber.
- Analysis of the skin entry and exit doses using 6MV FFF and 6MV FF photon beam.

2.4 Expected Outcome

The primary aim of this project involves assessing the feasibility of utilizing advanced radiotherapy planning methods for long size target volumes like craniospinal irradiation. These advanced treatment planning techniques have the potential to improve irradiation of the intended area while decreasing the amount of doses delivered to adjacent critical tissues. This project will help to develop solutions that can improve the treatment planning and delivery for craniospinal irradiation.

CHAPTER - 3

RESEARCH METHODOLOGY

OB-1

Retrospective Research of Dosimetric Comparison in Craniospinal

Irradiation for Medulloblastoma Tumors—An Institution

Assessment

3.1 MATERIAL AND METHOD

3.1.1 Patients

This is retrospective research included 20 patients with average-risk medulloblastoma. The patient's age range was 5–25 years. Patient's clinical characteristics are summarized in Table 3.1.

3.1.2 Patient Position

Patient's computed tomography (CT) scan has been performed in a supine position with three clamp thermoplastic orfit cast on Gemini GXL 16-slice Philips CT scanner machine with 3mm slice thickness. The patient is instructed to maintain the same position throughout the CT scan and treatment delivery to achieve precisional accuracy and conformity. CT images were transferred through digital imaging and communication in medicine (DICOM) to Accuray Precision version 2.0.1.1[5] and Monaco version 5.51.10 TPS. CT and magnetic resonance imaging (MRI) fusion has been performed for the delineation of cranial target, spinal target and OARs according to Radiation Therapy Oncology Group (RTOG) guidelines for medulloblastoma cancer by the radiation oncologist [102].

3.1.3 Contouring and dose prescription

The planning target volumes such as PTV_Brain, PTV_Spine, and GTV_Boost were contoured with a 3 mm equal margin to clinical target volumes (CTVs).

Table 3.1. Patient characteristics

Patient demographic	
Age (years)	Number of patients
<15	11
≥15	9
Sex	
Male	16
Female	4

The OARs are brainstem, optic chiasm, right lens and left lens, right and left eyes, right and left optic nerves, right and left parotid, oral cavity, mandible, right and left lung, heart, liver, kidney, bowel bag, rectum, bladder, and femoral heads. The target length range was 36.9 cm–75.7 cm with an average target length of 45.6 cm. The mean PTV_Brain, PTV_Spine, and GTV_Boost volumes were 1601.40 cc, 162.42 cc, and 59.43 cc, respectively.

In phase 1, the total prescribed dose to PTV-Brain and PTV-Spine was 36 Gy/20# (i.e., 1.8 Gy/#), and in phase 2, boost plan 18 Gy/10# (1.8 Gy/#) to GTV-Boost has been given. A total prescribed dose of GTV-Boost 54 Gy/30# was given.

3.1.4 Treatment planning

All plans were planned by the same experienced physicist, and contouring was performed by an experienced radiation oncologist. The minimum target coverage criterion was V95%, which means the target volume receives at least 95% of the prescribed dose. If the target volume receives a dose of more than 110% of the prescribed dose, then the area is considered a hot spot area, and if the dose is less than 95% of the prescribed dose, then the area is considered a cold spot area according to the International Commission on Radiation Units (ICRUs) [103]. Quantitative analysis of normal tissue effects in the clinic (QUANTAC 2010) guidelines gives the tolerance doses for critical organs such as brainstem, optic chiasm, lens, eye, optic nerve, parotid, lungs, heart, liver, kidney, bowel bag, rectum, bladder, and femoral head [104].

3.1.4.1 HIMRT

This treatment planning was performed for Accuray Radixact X9 linear accelerator machine with 64 binary MLCs and 6MV flattening filter (FF)- free photon beam with

Accuray Precision version 2.0.1.1[5] (Accuray, Madison, USA) treatment planning software (TPS). In Helical tomotherapy, treatment planning parameters like pitch and modulation factors play a very important role in dose distribution, plan quality and treatment efficiency. So for CSI, pitch of 0.287 is commonly used to reduce thread effect and ensure equal dose throughout target area and modulation factor typically in between 2.0 to 3.0 to get conformal dose while getting reasonable total treatment time. The treatment plans were generated with various planning parameters for the optimization of treatment plan such as field width— $2.5 \times 40 \text{ cm}^2$, plan mode—IMRT, delivery mode—helical, jaw mode—dynamic, modulation factor—2–3, pitch—0.29, convolution superposition dose calculation algorithm with medium dose calculation resolution, and grid spacing (mm)— $2.24 \times 3.00 \times 2.24$. In the constraint window, dose constraints were given to target volumes and critical OARs for the optimization of the treatment plan.

3.1.4.2 H3DCRT

In this treatment planning, the same parameters of HIMRT were used with delivery mode, which was helical 3DCRT. As it is 3DCRT helical mode, so dose was prescribed to targets only and does not contain any dose constraints for critical OARs.

3.1.4.3 VMAT

The treatment plans were generated for 6MV photon energy in Elekta Synergy (agility head) linear accelerator machine having photon energies of 4 MV, 6 MV, and 15 MV flattening filter (FF) and electron energies ranging from 4 MeV to 15 MeV using Monaco version 5.51.10 TPS. Treatment planning includes three full arcs with two to three rotations in each arc. Placement of these three arcs, first arc in the head and neck region, the second arc in the thorax region, third arc in the abdomen region. For optimization and dose calculation, the Monte Carlo algorithm was used. In the constraint mode plan, optimization was performed with a grid spacing (cm) of 0.30 and 3% statistical uncertainty per control point for target conformity and uniformity. In the sequencing parameters, the maximum number of control points per arc was 60, with a minimum segment width (cm) of 0.50 and medium fluence smoothing. The cumulative dose volume histogram (c-DVH) was evaluated to calculate conformity index (CI), homogeneity index (HI), heterogeneity index (HT), total TT, and volumetric doses to nearby critical OARs. For Planning target volumes, target

coverage with uniform dose distribution was $V_{100\%} \geq 95\%$, which is 100% target volume, should be covered with at least 95% of the prescribed dose and maximum dose in the target volumes should be less than 110% of the prescribed dose. OAR's dose tolerance was evaluated.

3.1.5 Plan evaluation

Plan evaluation gives confidence in accurate and precisional treatment delivery [105]. HI is defined as an analyzing tool to evaluate dose distribution uniformity levels within target volumes. The formula for HI is given as follows:

$$HI = \left(\frac{D_{max} - D_{min}}{D_{mean}} \right) \times 100 \dots\dots\dots 1$$

Where D_{max} , D_{min} is maximum dose and minimum dose in the target volume, and D_{mean} is mean dose in the target volume.

The ideal value for HI is zero, whereas the high value of HI indicates a nonuniform dose distribution. Hot spot and cold spot regions in the target volumes affect the HI.

CI is defined as an analyzing tool to check how the target volume is conformably covered by reference isodose lines. The formula is given as follows:

$$CI = \left[\frac{(V_{PTV\ Pres})^2}{(V_{PTVX\ Vpre})} \right] \times (V_{95\%}) \dots\dots\dots 2$$

Where V_{PTV} is the total target volume, $V_{PTV\ pres}$ is the volume of target covered by 95% isodose line, and V_{Pres} is the total target volume receiving 100% of the prescribed dose.

The ideal range of CI is 0–1, where CI near 1 shows better conformity of target volumes. HT is defined as a plan evaluation tool to check the dose gradient in the target volume. The formula is given as follows:

$$HT = \left(\frac{D_{1\%}}{D_{95\%}} \right) \dots\dots\dots 3$$

Where $D_{1\%}$ is the dose received by 1% of the target volume and $D_{95\%}$ is the dose received by 95% of the target volume. The ideal value of HT is 1.

For critical OARs, $D_{\max}$, $D_{\min}$, D_{mean} , and volumetric doses ($D_{80\%}$, $D_{50\%}$, $D_{30\%}$, and $D_{10\%}$) have been evaluated for all treatment plans. To get a better treatment plan, there should be good conformity, uniformity, and minimum possible doses of OARs. A TT comparison for all techniques is performed and tabulated in Table 2.

3.1.6 Statistical Analyses

Data were entered in Microsoft Excel and later imported into Statistical Package for the Social Science (SPSS V.22) for statistical analysis. Numerical variables were measured as mean and standard deviations. Repeated-measures analysis of variance (ANOVA), Wilks' lambda test, and Friedman's ANOVA tests, as appropriate, were used in analyzing significant differences for various dosimetric parameters. The Shapiro-Wilk test was used to check the normality of dosimetric parameters. A P value less than 0.05 is considered significant. For a normal distribution, repeated-measures ANOVA Wilks' lambda test was performed, and for normal distribution, Friedman's ANOVA test was performed.

OB-2

Helical Tomotherapy Delivery Analysis: A Successful Solution towards CSI Patients' Individualized Quality Assurance

3.2 MATERIALS AND METHODS

3.2.1. Treatment unit specifications:- For this study Accuray Radixact X9 accelerator setup was used with PTW 1500 Octavius setup Radixact X9 machines was equipped with MVCT image guided system having 6MV FFF filter free photon beam for treatment with dose rate of 104 mu/min and 3.5 MV for image guidance. Machine having 64 numbers of binary multi leaf collimator for intensity modulation and leaf projection of 6.25mm at isocenter. Machine having field width of 1x40 cm², 2.5x40 cm² and 5x40 cm² . Where 5cm is maximum longitudinal dimension and 40cm is maximum direction in lateral direction. For couch sagging, couch catcher assembly is

attached to back side of gantry. For treatment gantry rotation is 1-5 RPM and for imaging gantry rotation is 10-12 RPM.

3.2.2. MVCT Detector:-Megavoltage computed tomography detector is a device, which is use to take patients image before and after each treatment. It is basically locate opposite to the accelerator and placed on ring gantry. It is made up of 640 channels and each channel is having two parallel plate ionization cavities with pressurized xenon gas. MVCT detector array is placed at a distance of 145cm from source of high energy X-ray. Each detector channel is 1.24mm in transverse and 25.4mm in longitudinal direction. The imaging field of view at isocenter is 39.4cm. Therefore out of 640 channels only 576 are connected to the system for data acquisition and only 520 channels are used for imaging purpose.

3.2.3. PTW 1500 Detector Array:-The PTW 1500 detector array is consist of 1408 vented ionization chambers with 4.4mmx4.4mmx3mm (0.06 cm^3) volume all the chambers are arranged in a matrix of 27x27 covering area of $27 \times 27 \text{ cm}^2$ center to center detector spacing is 71mm. The Octavius phantom is made up of polystyrene in octagonal shape with physical density is 1.04 g/ cm^3 and relative electron density is 1.00 phantom dimension is 32cm height, 32cm length and 32cm width. The measuring assembly include detector array including electric devices, an array interface and data acquisition system. The central cavity $30 \times 30 \times 2.2 \text{ cm}^3$ is used to insert 2D 1500 detector array. Semi-cricoids air gap present at the base of Octavius phantom is use to correct the inerrant under response of detector array when radiation is posterior falling on phantom. For dose calculation Octavius phantom was scanned with 1500 detector array. PTW Verisoft software with version 5.0 was used for data analysis. The 2D detector array was calibrated for absolute dosimetry in Co60 photon beam setup. Before measurement with 2D detector array cross calibration has to be done. In cross calibration procedure, dose of 2Gy was delivered on the phantom and cross calibration and applied on entire matrix of detectors. The daily output of accelerator should be corrected for corrected measurement.

3.2.4. Delivery Analysis – 3D Dose Reconstruction from MLC Leaf Open Time.

3D dose reconstruction from MLC-LOTS as Accuray Radixact X9 machine is equipped with MVCT detector which is used to analyses exit dose with the help of

delivery analysis software. Each point in sinograms represents a multileaf collimator. In graphical representation of LOTS, 100 values indicate that multileaf collimator will open for all projections and 50 value represents multileaf will be open for 50% of leaf open time for that projection. The planned LOTS represents leaf open time for each leaf and for each projections of treatment plan reconstructed LOTS represents leaf opening time for each leaf according to reconstructed from pulse by pulse MVCT detector data. The plan and reconstructed sinograms compared by side by side percent difference and gamma values. Positive difference indicate reconstructed dose is high than planned dose negative difference indicate reconstructed dose is less than planned dose. While delivering patient specific quality assurance without phantom on the treatment couch, MVCT detector collect the exit dose and plot sinograms according to exit dose. These sinograms are reconstructed from signal pulses getting through central detector channels, which are corresponding to one MLC leaf. These signal pulses are divided into projection bins. For every projection, LOT was calculated based on values more than set threshold values. After delivery planned patient specific quality assurance, multileaf collimators LOTS were analyzed in delivery analysis system.

3.2.5. Craniospinal Irradiation Treatment Planning:- This reproductive study of 20 craniospinal irradiation patients. Helical Intensity Modulated Radiation Therapy (HIMRT) technique was used for plan treatment planning with Accuray precision version 2.1.1.1, Accuray, Inc. Sunnyvale (USA) treatment planning system (TPS).signal plan was used for PTV Brain and PTV Spine. Radixact X9 can treat the patient up to 135 cm in Y direction. The planning parameters are shown in table 1, Field with ,Pitch and modulation factor are chosen in such a way that it gives better plan quality and less dose to OAR's. Every patient was planned for 36 Gy/18#, 2Gy/# to PTV_Brain and PTV_Spine. The treatment plan was optimized so that planning target volumes gets maximum possible dose and simultaneously Organs at risk gets minimum possible dose. To reduce leaf latency errors, leaf open time less than 20ms as beam eliminated from final dose calculations. Before delivery of treatment plan, it was evaluated of Medical Physicist and Radiation Oncologist to achieve better clinical outcomes.

Table 3.2. Treatment planning parameters of helical intensity modulated radiation therapy (HIMRT) treatment planning technique for Non-CSI and CSI patients.

NON CSI PATIENTS				
NO OF PATIENTS	SITES	TREATMENT PLANNING PARAMETER		
		FIELD WIDTH (CM)	PITCH	MODULATION FACTOR
1	Ca. Buccal Mucosa	2.5	0.43	3
2	Ca. Tongue	2.5	0.43	3
3	Ca. Breast(Left)	2.5	0.296	2.5
4	Ca Rectum	2.5	0.43	3
5	Ca Esophagus	2.5	0.43	2.4
6	Ca Breast(Right)	2.5	0.282	2.5
7	Ca cervix	2.5	0.43	3
8	Ca prostate	2.5	0.43	3
9	Ca maxilla	2.5	0.43	3
10	Ca GBS	2.5	0.43	3
CSI PATIENTS				
NO OF PATIENTS	TREATMENT PLANNING PARAMETER			
	FIELD WIDTH (CM)	PITCH	MODULATION FACTOR	
1	2.5	0.287	2.6	
2	2.5	0.287	3	
3	2.5	0.287	2.4	
4	2.5	0.287	2.4	
5	2.5	0.287	2.6	
6	2.5	0.287	2.8	
7	2.5	0.287	2.2	
8	2.5	0.287	2.4	
9	2.5	0.287	2.6	
10	2.5	0.287	2.4	
11	2.5	0.287	3	
12	2.5	0.287	2.4	
13	2.5	0.287	2.4	
14	2.5	0.287	2.8	
15	2.5	0.287	2.2	
16	2.5	0.287	3	
17	2.5	0.287	2.4	
18	2.5	0.287	2.2	
19	2.5	0.287	2.4	
20	2.5	0.287	2.6	

3.2.6. Validation of Delivery Analysis for 3D Dose Reconstruction: - Delivery analysis system is utilized to reconstruct the 3Dimensional Dose distribution from MVCT Detector. For this study purpose the practicality of delivery analysis system was checked for 10 non _CSI patients representing four head and neck patient, three thoracic region patients and three pelvic region patients. The planning parameters as shown in [Table 3.2](#). Before delivery of treatment plan, it is very important to for form patient specific quality assurance of each patient to check the difference between planned and delivered dose. Patient specific quality assurance of each non _CSI patient has been generated on PTW 1500 detector array (Germany) to measure 2D fluence and compare this fluence with planned fluence. Patient specific quality assurance for absolute point dosimetry with cheese phantom (Accuray, Inc, Sunnyvale, USA with 0.053CC ionization chamber Extra din AISL standard imaging, Inc. Middleton, WI) has been used Verisoft software version 8.1 is used to compare planned fluence and measured fluence 2D gamma index is calculated considering 3% dose difference (DD) and 3mm distance to agreement (DTA). According to institute PSQA protocol, QA is passed if gamma index is 97%. The QA plans generated for absolute point measurement with cheese phantom and 2D fluence and with Octavius phantom have been delivered on Radixact X9 machine without anything on the treatment couch. Exit fluence calculated by MVCT Detector is used to reconstruct the 3D Dose distribution by 3D gamma index analysis or dose volume histogram (DVH) and verification of point dose. For 3D gamma index analysis tolerance criteria of 3% DD and 3mm DTA has been considered. To check maximum and minimum doses to planning target volumes D98% and D2% of target volumes are calculated from cumulative planned and reconstructed DVH's. The implementation of PSQA based on MLC_leaf open time sinograms has been extended for 20 CSI patients. To calculate absolute doses at four sites like brain, neck, thorax and abdomen region patient specific quality assurance plans were generated for approved treatment plans using standard imaging cheese phantom and standard imaging AISL 1 ion chamber. These plans were delivered with cheese phantom and AISL1 ion chamber to calculate absolute doses on Radixact X9 machine.

To reconstruct 3D dose distribution on patient CT from multileaf open time sinograms, patient specific quality assurance plans were generated for clinically approved plans using PTW 1500 detector array and Octavius phantom. These patient specific quality assurance plans were delivered on Radixact X9 machine without anything on the treatment couch MVCT detector is use to collect transmitted fluence from treatment couch which further use to reconstruct 3D dose distribution. In this study comparisons has been done a) Accuray Precision TPS planned dose and absolute dose with cheese phantom and AISL 1 ion chamber, b) TPS planned and 3D^v reconstructed dose distribution from delivery analysis using leaf open time sinograms and c) TPS planned and 3D reconstructed dose distribution LOT from DVH of D_{2%} and D_{98%}. Setup of PTW Octavius phantom with detector array in Radixact X9 is shown in Fig. 3.2.



(a)

(b)

Fig. 3.2 (a) Setup of PTW Octavius phantom with detector array in Radixact X9 Tomotherapy machine for 2D gamma index. (b) Cheese phantom with AISL1 ion chamber for absolute point dose measurement.

OB-3

Evaluating the Megavoltage Computed Tomography (MVCT) **Weighted Computed Tomography Dose Index (CTDI_w)**

3.3 METHOD AND MATERIALS

For this study Accuray Radixact X9 Linear accelerator machine having single 6 MV FFF radiation beam for treatment and 3.5 Mega Voltage photon beam has been used for imaging procedures as shown in Fig. 3.3. Before each treatment MVCT was taken to verify the reproducibility of set up positions. To calculate patient's MVCT dose, cheese phantom with AISL ion chamber 0.053cc volume and tomo electrometer standard imaging has been used. Cheese phantom have 30cm diameter and 18cm length with holes for ion chamber insertion. MVCT was taken for 7mm, 100mm and 180mm scan length. All measurements were taken in fine, normal and coarse modes. Ion chambers were positioned at center of phantom (1cm from center) and at the cheese phantom's periphery (1cm in from phantom) at positions like anterior, posterior, right and left peripheral positions as shown in Fig. 3.4.

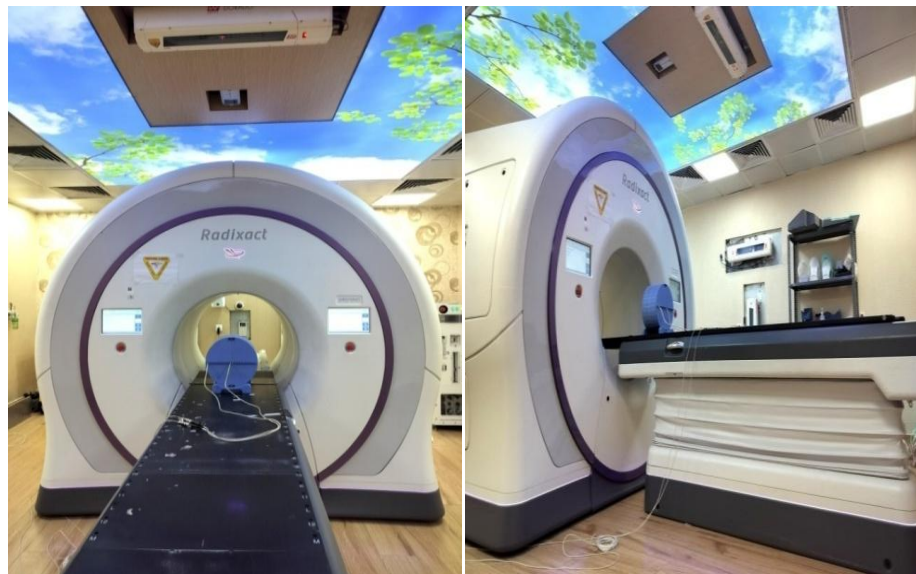


Fig. 3.3. Anterior and lateral view of Accuray Radixact X9 linac machine having 6 MV flattening filter free beam with AISL ion chamber inserted at center and right side of cheese phantom.

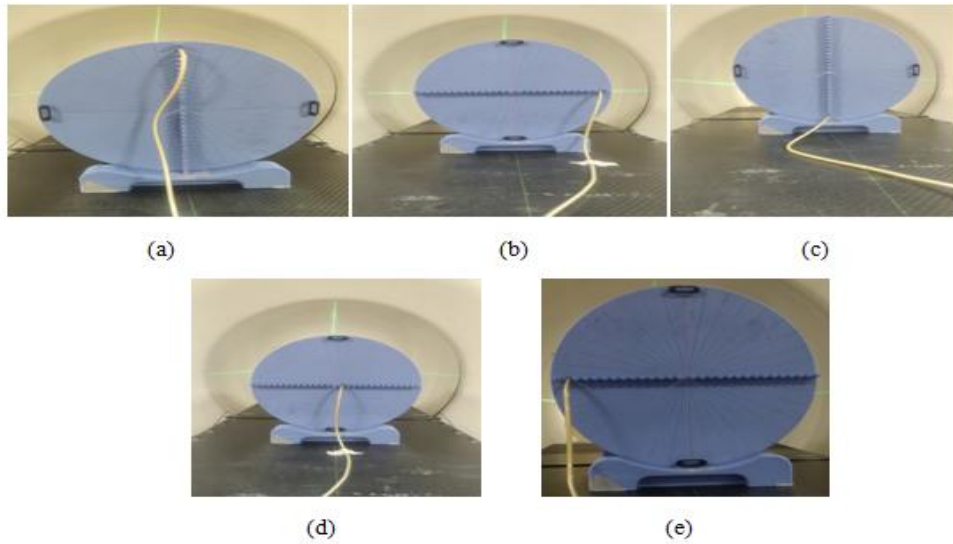
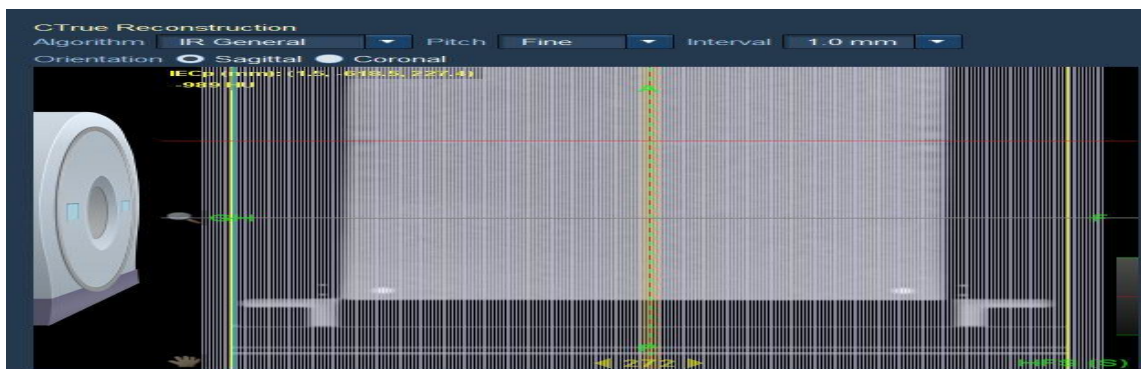
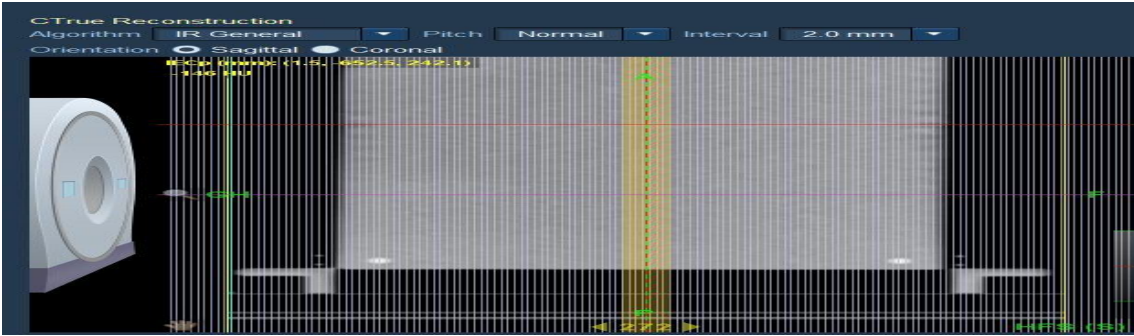


Fig. 3.4. AISL1 ion chamber positions in cheese phantom. (a) Ion chamber at anterior position. (b) Left lateral position. (c) Posterior position. (d) At center at cheese phantom. (e) Right lateral position.

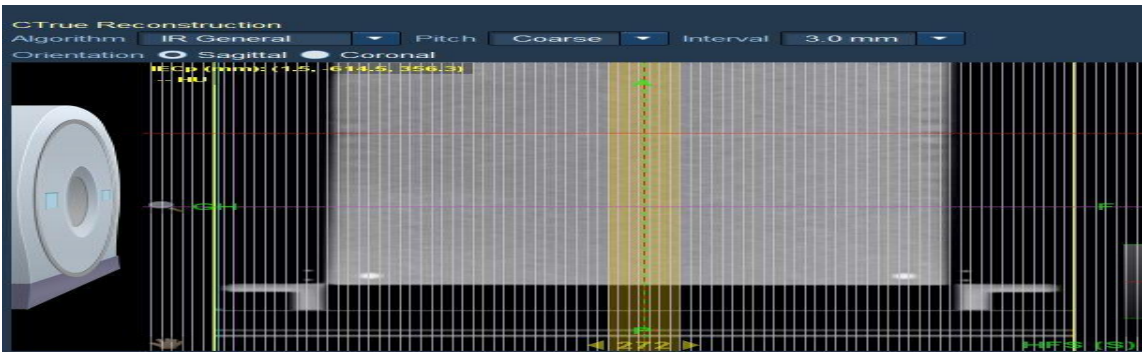
Image reconstruction was done with iterative algorithm and automatic matching method. This study was performed for head and neck site. Ionization chamber with 0.053cc volume having outer diameter 6.35mm and chamber sensitive length of 4.4mm have been used, which was calibrated for Co^{60} beam. For helical delivery CTDI_{100} and $\text{CTDI}_{\text{Weighted}}$ (CTDI_w) has been calibrated using center and periphery dose. The procedure was performed 5 times for stability and reproducibility as shown in Fig. 3.5.



(a)



(b)



(c)

Fig. 3.5. Imaging of cheese phantom in different modes. (a) Fine mode having 1mm slice thickness. (b) Normal mode with 2mm slice thickness. (c) Coarse mode with 3mm slice thickness.

Delivered dose was calculated with Multislice Average Dose (MSAD) [106] using equation 1.

$$\text{MSAD} = M * N_{\text{DW}} * K_{\text{QQ0}} * K_{\text{TP}} \dots \dots \dots 1$$

Where, M = Meter reading in pC, N_{DW} = Absorbed dose to water calibration factor, K_{QQ0} = Beam quality factor (1.003), K_{TP} = Temperature pressure correction factor.

CTDI_w calculation using equation 2, assumes that the radiation decreases linearly from outside to the center and calculated as,

$$\text{CTDI}_w = \frac{1}{3} (\text{Radiation at center}) + \frac{2}{3} (\text{Radiation at periphery}) \dots \dots 2$$

It is then divided by the length of scan to give CTDI per slice.

Pitch is defined a table movement after 360° rotation. Conversion of CTDI_w in helical mode is called Volume CTDI (CTDI_{Vol}) in equation 3.

$$CTDI_{Vol} = \frac{CTDI_w}{Pitch}.....3$$

The Larger the pitch, the lower will be the dose representing equation 4.

$$DLP = CTDI_w * Scan\ length.....4$$

DLP = Dose length product (mGycm). DLP provides a better measure of the stochastic risk to the patient after a given CT. DLP can be converted into the effective dose. Imaging time for7 slices in fine, normal and coarse mode was 21.5seconds at center and periphery. To ensure the reproducibility, reliability and minimize the chances of random errors, measurements have been taken three times. So this approach enhances confidence, precision of dosimetric outcomes. Absorbed dose was measured at anterior, posterior, right, left and center of phantom for 0.7 cm, 10 cm and 18 cm in fine, normal and coarse pitch mode with 1mm, 2mm and 3mm slice thickness respectively. Secondly, absorbed dose measurement has been taken at 1, 4, 6, 8, 9 and 12 cm depths in phantom with scan length for 7mm.

OB-4

Quantitative Examination of Integral Doses and Skin Entry Exit Doses among Patients Received Craniospinal Irradiation Utilizing Various Radiation Treatment Delivery Approaches.

3.4 METHOD AND MATERIALS

This is a retrospective type of study. For this study, 20 patients from CSI were taken. The patient’s CT scan was done on a Philips Gamine GXL 16-slice CT machine with 3mm of slice thickness. CT images were transferred to Accuracy Precision version- 2.0.1.1(5) and Monaco version 5.51.10 Treatment Planning Systems (TPS). A radiation oncologist delineated the target and OAR according to the RTOG protocol (Radiation Therapy Oncology Group-0319) guidelines for Cranial medulloblastoma cancer [107]. The skin ring was created by giving a 3mm negative margin to the skin.

The purpose of making a skin ring is to evaluate the actual dose delivered to the skin at 3 mm on the inner side. Point dose has been calculated for five dose points at the forehead, chin level, chest level, abdomen, and pelvic region to calculate average entry-exit doses. The mean volume for PTV_Brain was 1601.401cc; PTV_Spine was 147.662cc, and Boost_GTV was 200.10cc. Treatment plans were created for Helical-Intensity Modulated Radiation Therapy (HIMRT), Helical Three-Dimensional Conformal Radiation Therapy (3DCRT) and Volumetric Modulated Arc Therapy (VMAT) with Accuray Precision version 2.0.1.1(5) software Accuray, Morison USA and Elekta Monaco software version 5.51.10. In the first phase, a total dose of 36Gy/20#, 1.8Gy/# was given to the PTV-Brain and PTV-Spine. In phase-2, 18 Gy dose in 10 fractions was given to Boost_GTV. In all treatment planning required target coverage for PTV_Brain and PTV_Spine was checked with V95% (Target coverage with minimum 95% of the prescribed dose), and OAR tolerance doses were checked according to QUANTEC data -2010 (Quantitative Analysis of Normal Tissue Effect in the Clinic) [108]. Treatment was delivered using the helical intensity modulated radiation therapy technique, which is beneficial in terms of no hot spot or cold spot compared to other techniques.

3.4.1 Treatment planning Techniques

3.4.1.1 Helical-Intensity Modulated Radiation Therapy (HIMRT) & Helical Three-Dimensional Conformal Radiation Therapy (H3DCRT)

HIMRT & 3DCRT plans were created for Accuray Radixact X9 Tomotherapy machine with Accuray Precision Version 2.0.1.1 [5] Accuracy Madison USA treatment planning software. All treatment plans were created in IMRT and 3DCRT Mode; The Pitch was 0.293, the Modulation factor was between 2-3, the Convolution Superposition Algorithm for dose calculation, and the field width of 2.5 x 40 cm² was used with 64 numbers of binary MLCs and 6MV Flattening Filter Free (FFF) photon beam.

3.4.1.2 Volumetric Modulated Arc Therapy

VMAT plans were generated with Elekta Synergy (Agility) LINAC with Elekta Monaco version 5.5.1.10 treatment planning software. To generate the patient treatment plans, a 6 MV Flattening filter photon beam and 80 pairs of MLCs with 0.5

cm width at the isocenter were used. To cover the whole target area, three arcs were inserted with two to three rotations per arc according to requirement. The first arc was inserted at the head and neck region, the second arc was at the thoracic region, and the third arc at the abdomen region was inserted. The Monte Carlo algorithm was used to optimize the plan. The grid spacing was 0.30 cm with 3% statistical uncertainty per control point, the minimum segment width was 0.5 cm, and the medium fluence smoothing method was adopted. The aim of this study is to quantify the various volumetric doses for Skin and Skin Ring (Dmax, Dmean, D80%, D50%, D30%, and D10%), Skin entry-exit point doses, and integral dose to target volumes.

3.4.2 Treatment Plan Evaluation

Treatment plans were evaluated by Medical Physicist with Radiation Oncologist as per guidelines of quantitative analysis of normal tissue effects in the clinic (QUANTEC – 2010). Cumulated Dose Volume Histograms (DVH) were used to evaluate various OARs volumetric doses (Dmax, Dmean, D80%, D50%, D30%, and D10%) and target doses (D1% and D95%). The minimum target coverage criteria were V95% (Target coverage with at least 95% of the prescribed isodose curve) and considering the hotspot region more than 110% of the prescribed dose. Integral Dose (ID) to target volumes and the whole body is defined as the product of absorbed dose D (Gy) and target volume. Integral dose was calculated with this mathematical equation, Integral Dose (ID) = D (Gy) x Vol (L), Where D (Gy) is the mean absorbed dose to target (Gy), Vol (L) is the target volume (L is liter) [109] [110]. In this study, the mathematical equation used for integral dose calculation is the same as that used in the Aoyama et al. study.

3.4.3 Statistical Analysis

Data was collected for all patients and processed with Microsoft Excel software, which was then analyzed in the Statistical Package for the Social Science (SPSS V.22) software. Mean and standard deviations were calculated. Repeated measure ANOVA Wilks's Lambda Test and Friedman's ANOVA tests, as appropriate, were performed to assess significant differences for various dosimetric parameters. The normality of dosimetric parameters was checked using the Shapiro-Wilk test. If the P-value is less than 0.05, then it will be considered significant. Repeated measure ANOVA Wilks's

Lambda test was performed for normal distribution, and Friedman's ANOVA test was performed for non-normal distribution.

CHAPTER-4

RESULTS AND DISCUSSION

OB-1

Retrospective Research of Dosimetric Comparison in Craniospinal Irradiation for Medulloblastoma Tumors—An Institution Assessment

4.1 RESULTS

In this study, comparative dosimetric analysis has been performed for Boost_GTV, PTV-Brain, and PTV-Spine shown in [Table 4.1](#), [Fig. 4.1](#) and [4.2](#) based on CI, HI, HT, TT, monitor units, and doses to critical organs. For planning target volumes, Dmax, Dmin, Dmean, V95%, VPres, V107%, V110%, D1%, D95%, HI, CI, and HT have been calculated. For critical OARs, Dmax, Dmean and D30% have been calculated and tabulated in [Table 4.2](#). All techniques, such as HIMRT, H3DCRT, and VMAT, give uniform and conformal target coverage; however, HIMRT shows better OAR sparing. The total treatment time for phase 1 and for phase-2 is given in [Table 4.3](#). From [Fig. 4.3a](#) for phase 1 plans, VMAT plans show lesser TT compared with HIMRT and H3DCRT treatment planning. From [Fig. 4.3b](#) for phase 2 plans, HIMRT and H3DCRT plans are with lesser time compared with VMAT treatment planning. From [Fig. 4.4a](#) and [Fig. 4.4b](#) for phase 1 and phase 2, monitor units (MUs) are lesser in VMAT treatment plans compared with HIMRT and H3DCRT treatment plans. Helical treatment plans required more MUs because of the smaller field width and slice-by-slice treatment.

4.2 OAR's doses

Some OARs are very near to target volumes, so it is very important to spare these OARs as much as possible and reduce the chance of getting late radiation side effects. *P* values are calculated for HIMRT, H3DCRT, and VMAT. From [Table 4.2](#), the comparison shows that doses of OARs are less in HIMRT as compared to H3DCRT and VMAT, whereas VMAT treatment planning shows the highest doses for optic chiasm, brainstem, right eye, left eye, right optic nerve, left optic nerve, kidneys, and spinal cords. There is more conformal and homogenous dose

distribution in HIMRT compared with H3DCRT, which shows more spillage. Whole-body exposure is higher in the helical treatment technique compared with the VMAT technique. This might be due to radiation beams entering from multiple sides, which results in an abrupt increase in the volume of low-dose region. The whole-body exposure can cause late effects on patients. So, during the treatment plan, one should take care of whole body exposure levels.

Table 4.1. Dosimetric comparison of Dmax (maximum dose), Dmean (mean dose), conformity index (CI), Homogeneity index (HI), Heterogeneity index (HT), V_{95%}(volume receiving 95% of prescribed dose) and V_{107%}(volume receiving 107% of prescribed dose) for GTV_BOOST, PTV_BRAIN and PTV_SPINE in HIMRT, H3DCRT and VMAT treatment planning techniques.

Target	Dosimetric parameters	HIMRT	H3DCRT	VMAT	P- Value HIMRT Vs H3DCRT Vs VMAT
GTV_BOOST	Dmax(Gy)	59.50±1.42	58.52±2.10	58.8±0.158	0.00*

		4	0		
	Dmean(Gy)	55.00±0.50 0	54.73±0.71 7	55.12±0.420	0.00 [#]
	CI	1.035±0.01 6	1.04±0.016	1.08±0.05	0.001 [#]
	HI	0.80±0.090	0.44±0.223	0.56±0.105	0.00 [#]
	HT	1.27±0.006	1.26±0.009	1.07±0.009	0.00 [*]
	V _{95%}	99.34±0.27 9	99.71±0.14 0	98.67.33±0.950	0.00 [#]
	V _{107%}	0.81±1.161	0.23±0.541	0.91±0.972	1.00 [#]
PTV_BRAIN	Dmax(Gy)	40.98±1.43 5	40.03±2.06 5	39.74±0.135	0.00 [*]
	Dmean(Gy)	36.85±0.46 6	36.59±0.71 7	36.81±0.413	0.001 [#]
	CI	1.02±0.016	1.04±0.015	1.11±0.090	0.00 [#]
	HI	0.73±0.088	0.39±0.208	0.43±0.102	0.00 [#]
	HT	1.51±0.013	1.50±0.017	1.09±0.018	0.00 [#]
	V _{95%}	98.7±0.556 0	99.42±0.28 1	97.69±1.616	0.00 [#]
	V _{107%}	0.81±1.161	0.23±0.514	0.91±0.972	0.00 [#]
PTV_SPINE	Dmax(Gy)	37.66±0.47 3	37.38±1.12 9	38.77±0.367	0.00 [#]
	Dmean(Gy)	36.88±0.32 6	36.56±0.69 7	35.36±6.69	0.00 [#]
	CI	1.00±0.004	1.01±0.013	1.07±0.039	0.00 [#]
	HI	0.07±0.043	0.06±0.070	0.23±0.183	0.00 [#]
	HT	1.10±0.12	1.11±0.121	1.06±0.007	0.043 [#]
	V _{95%}	99.98±0.07 0	99.95±0.24 6	99.83±0.219	0.00 [#]
	V _{107%}	0.01±0.045	0.16±0.574	0.05±0.0080	0.001 [#]

Table 4.2. Dosimetric comparison of OAR's doses ($D_{\max}$, D_{mean} , $D_{80\%}$, $D_{50\%}$, $D_{30\%}$ and $D_{10\%}$) and p-values for HIMRT, H3DCRT and VMAT treatment planning technique. Where * represents Repeated measure ANOVA Wilks's Lambda Test and # represents Friedman's ANOVA Test.

OARS	Dosimetric parameters	HIMRT	H3DCRT	VMAT	P- Values HIMRT Vs H3DCRT Vs VMAT
Optic chiasm	Dmax	42.16±6.144	41.51±7.38	47.43±4.880	0.007#
	Dmean	40.98±5.278	40.34±5.774	44.82±4.201	0.063#
	D _{30%}	44.97±4.335	44.96±4.497	45.43±4.499	0.899*
Brainstem	Dmax	44.36±9.014	43.60±9.032	57.57±3.384	0.00#
	Dmean	42.87±8.191	42.52±8.379	53.47±1.227	0.00#
	D _{30%}	53.40±5.647	53.92±4.195	54.27±6.691	0.00#
Rt lens	Dmax	6.66±1.974	12.99±5.288	11.36±0.998	0.00*
	Dmean	5.72±1.480	11.50±4.661	9.52±0.711	0.00*
	D _{30%}	6.83±0.771	13.01±4.463	9.77±0.724	0.00*
Lt lens	Dmax	4.96±2.702	10.30±3.802	11.19±0.846	0.00#
	Dmean	3.98±0.763	10.51±3.478	9.65±0.606	0.00*
	D _{30%}	4.35±0.473	11.29±2.963	9.86±0.599	0.00*
Rt eye	Dmax	22.98±3.506	28.51±3.780	36.56±3.186	0.00#
	Dmean	9.42±2.098	16.37±4.483	17.41±1.918	0.00*
	D _{30%}	11.13±2.574	19.37±2.048	20.10±3.656	0.00*
Lt eye	Dmax	20.39±2.827	26.48±4.554	36.16±2.342	0.00*
	Dmean	7.25±0.886	15.11±3.360	17.24±1.474	0.00*
	D _{30%}	8.42±0.912	17.92±3.720	19.92±2.446	0.00*
Rt optic nerve	Dmax	38.26±4.442	38.52±4.280	44.45±3.726	0.00#
	Dmean	25.41±3.243	30.29±3.816	35.71±2.545	0.00*
	D _{30%}	31.68±3.501	35.13±2.707	39.64±2.467	0.00*
Lt optic nerve	Dmax	36.63±8.502	38.49±4.125	43.83±3.526	0.00#
	Dmean	14.72±4.650	29.48±5.553	35.64±3.021	0.00*
	D _{30%}	18.94±11.271	34.20±6.309	39.34±2.421	0.00#
Rt parotid	Dmax	23.36±3.927	33.39±4.386	32.18±3.655	0.00#
	Dmean	11.00±0.748	17.93±2.913	14.71±2.082	0.00*
	D _{30%}	12.58±1.371	21.92±4.665	16.85±2.694	0.00#
Lt parotid	Dmax	12.76±5.892	32.16±5.693	35.13±6.712	0.00#
	Dmean	4.47±0.766	17.58±4.617	16.1±2.868	0.00#
	D _{30%}	5.18±0.804	21.71±6.298	18.71±4.504	0.00*
Rt lung	Dmax	25.12±4.113	27.21±6.909	25.68±3.439	0.00#
	Dmean	5.75±0.637	6.89±1.263	6.75±0.391	0.00*
	D _{30%}	5.99±0.725	7.40±1.358	7.23±0.47	0.00*
Lt lung	Dmax	21.37±3.717	24.48±4.464	22.45±3.429	0.00*
	Dmean	5.58±0.434	6.30±1.214	6.32±0.554	0.00*

	D _{30%}	6.03±0.362	6.97±1.262	6.76±0.501	0.00*
Rt kidney	Dmax	8.82±2.594	12.36±4.014	13.58±3.256	0.00#
	Dmean	3.53±1.168	8.02±5.457	7.13±1.316	0.00#
	D _{30%}	3.84±1.311	7.76±2.825	71.76±1.476	0.00#
Lt kidney	Dmax	12.29±3.711	12.93±5.572	13.60±3.627	0.016*
	Dmean	5.5±1.400	7.21±2.502	7.15±1.342	0.00#
	D _{30%}	5.76±1.525	7.99±2.781	7.80±1.487	0.00#
Heart	Dmax	9.56±2.827	10.50±2.792	10.79±3.180	0.024#
	Dmean	3.97±0.955	5.22±1.486	5.65±1.304	0.00#
	D _{30%}	4.34±1.042	5.67±1.631	6.11±1.483	0.00#
Liver	Dmax	11.82±3.446	14.17±5.36	14.43±3.306	0.00#
	Dmean	4.05±1.037	5.20±1.61	5.32±0.23	0.00#
	D _{30%}	4.51±1.166	5.58±1.703	5.70±0.899	0.00#
Bowel bag	Dmax	10.40±4.837	9.87±4.768	9.21±3.713	0.344*
	Dmean	2.99±1.684	3.60±2.349	2.58±1.702	0.068*
	D _{30%}	3.73±2.173	4.15±2.666	3.32±2.149	0.021#
rectum	Dmax	0.78±0.493	0.84±0.638	0.56±0.506	0.00#
	Dmean	0.44±0.712	0.64±1.510	0.29±0.711	0.00#
	D _{30%}	0.48±0.735	0.70±1.609	0.32±0.730	0.00#
bladder	Dmax	0.58±0.338	0.57±0.303	0.47±0.502	0.00#
	Dmean	0.26±0.153	0.43±0.681	0.20±0.155	0.00#
	D _{30%}	0.29±0.177	0.32±0.243	0.23±0.166	0.00#
Rt femur	Dmax	0.26±0.147	0.28±0.173	0.21±0.130	0.00#
	Dmean	0.13±0.088	0.14±0.101	0.11±0.135	0.00#
	D _{30%}	0.15±0.097	0.14±0.055	0.10±0.073	0.00#
Lt femur	Dmax	0.25±0.165	0.26±0.183	0.20±0.149	0.00#
	Dmean	0.13±0.091	0.13±0.100	0.08±0.064	0.00#
	D _{30%}	0.15±0.102	0.13±0.060	0.10±0.175	0.00#
Spinal cord	Dmax	38.15±1.262	37.88±1.544	42.73±4.941	0.00#
	Dmean	36.99±0.502	36.71±0.795	37.23±0.490	0.00#
	D _{30%}	37.07±0.53	36.80±0.788	37.29±0.253	0.00#

Table 4.3. Mean treatment time for Phase-1 and Phase-2 in HIMRT, H3DCRT and VMAT. Where * represents Repeated measure ANOVA Wilks’s Lambda Test and # represents Friedman’s ANOVA Test.

Treatment Time(min)	HIMRT	H3DCRT	VMAT	P- Value HIMRT Vs H3DCRT Vs VMAT
Phase 1	17.77±3.974	14.83±3.750	9.72±0.713	0.00 [#]
Phase2	1.99±0.306	1.68±0.326	3.39±0.918	0.00 [*]

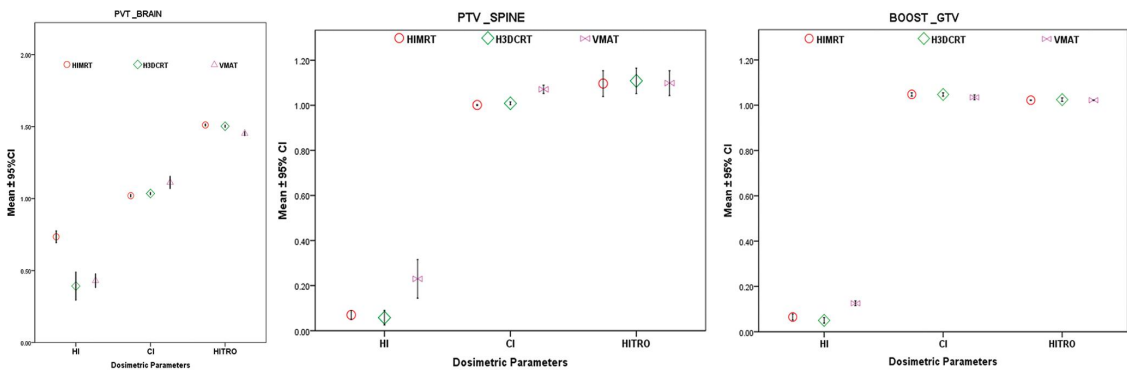


Fig. 4.1. Representation of homogeneity index, conformity index, and heterogeneity index for PTV_ Brain, PTV-Spine, and Boost_GTV for HIMRT, H3DCRT, and VMAT treatment techniques. In x-direction—dosimetric parameters (HI, CI, and HT) and y-direction—mean $\pm$ 95% of confidence interval (CI).

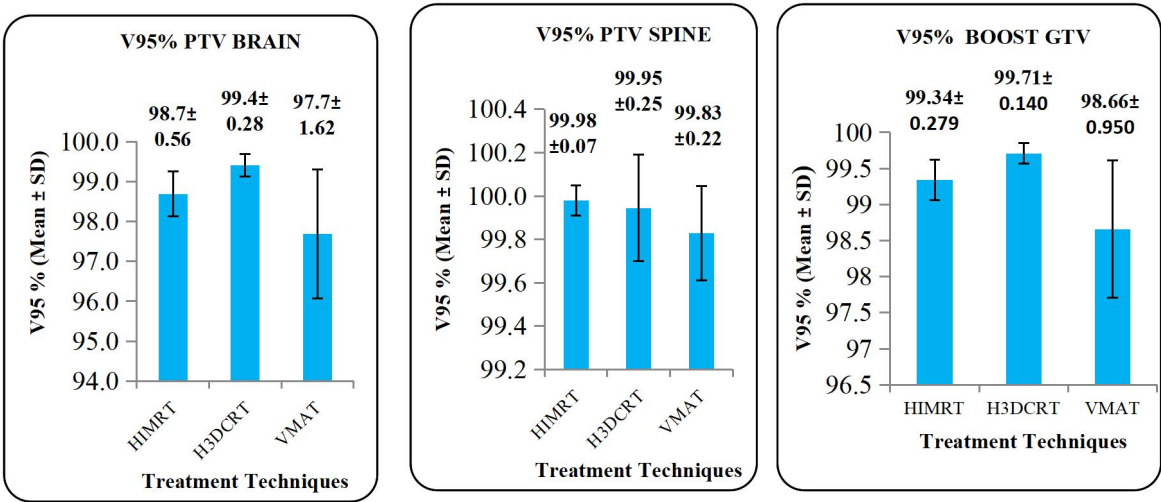
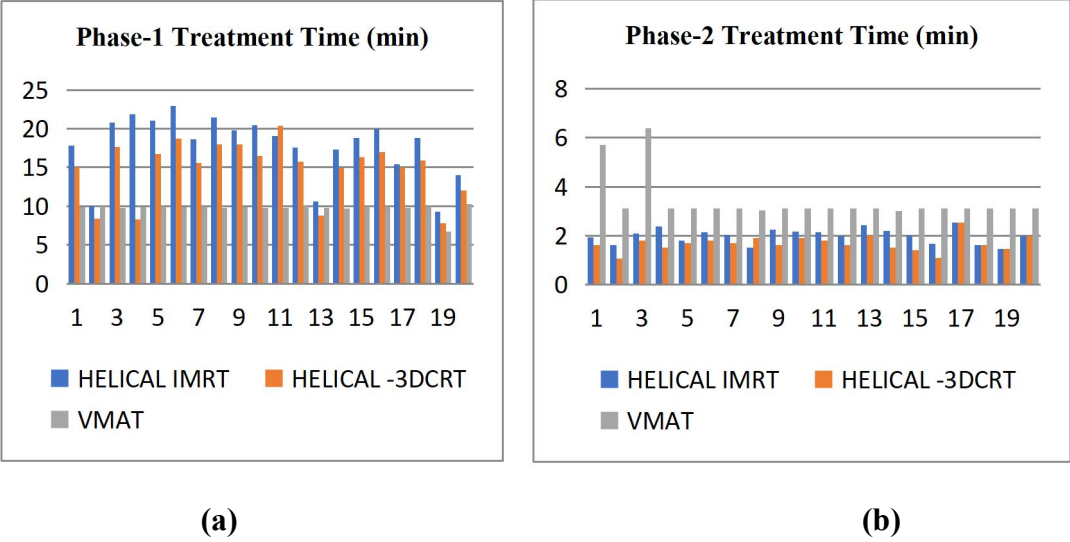


Fig. 4.2. Graphical representation of V_{95%} (Volume receiving 95% prescribed dose) to PTV_Brain, PTV_Spine and Boost_GTV in HIMRT, H3DCRT and VMAT.



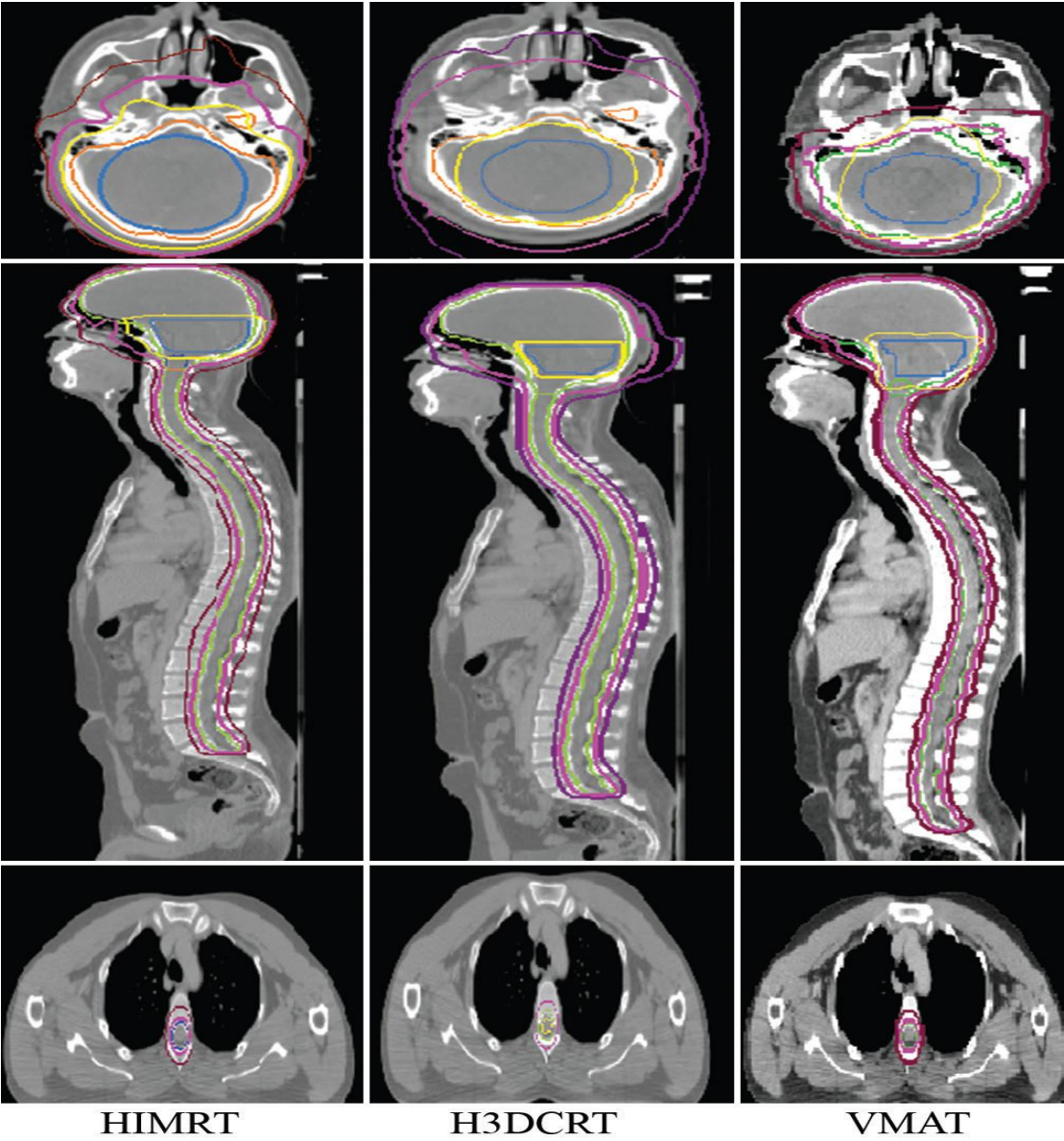


Fig. 4.5. Dosimetric comparison of dose distribution in HIMRT, H3DCRT, and VMAT treatment is a planning technique. This shows axial CT scan view of the head and neck and abdomen region and a sagittal view of PTV_Brain and PTV_Spine. PTV_Brain and PTV_Spine are contoured in green color and Boost_GTV in blue color. Volume receiving 95% of the prescribed dose (V95%) showing 34.2 Gy (V95%)— pink color, 30 Gy—brown color, and 51.3 Gy—yellow color. HIMRT— helical intensity- modulated radiation therapy, H3DCRT—helical three- dimensional radiation therapy

4.3 DISCUSSION

This discussion compared CSI with H3DCRT, HIMRT, and VMAT and correlates the outcomes with previous studies. HIMRT demonstrated best conformal doses among all the evaluated treatment techniques. Helical treatment techniques give better performance resulting from simultaneous movement of the gantry and treatment couch. However, in a similar study conducted by Lee *et al.* based on a comparison of the conventional RT technique with smart arc based VMAT planning for CSI patients with a dose prescription of 23.4 Gy in 13#, CI was found to be 1.22 for the conventional RT and 1.04 for VMAT. Furthermore, results show a decrease in max and mean doses for the optic nerve, esophagus, heart, and thyroid critical organs when compared to conventional treatment planning techniques [111]. Seppala *et al.* have compared tomotherapy and conventional IMRT planning for CSI patients using a single plan with the dynamic split field IMRT technique and improved target dose homogeneity compared with conventional 3DCRT technique [112]. The difference in results may be due to the preference of target and OARS dose constraints. Sharma *et al.* have conducted a study of dosimetric comparison of tomotherapy, 3DCRT, and IMRT for CSI pediatric and adult patients. The CI with helical tomotherapy for PTV_Spine was 0.83 and that for PTV_Brain was 0.96. Small segment size and small field width in IMRT and tomotherapy increased whole-body integral doses and TT [113].

In another research conducted by Zong-Wen *et al.*, they have conducted a dosimetric comparison for CSI patients by helical tomotherapy, 3DCRT, and VMAT technique and resulted in better CI (0.69) and HI (1.05) with helical tomotherapy compared with 3DCRT and VMAT [114].

In our study, HIMRT shows longer TT and MUs compared with other techniques. This factor can create mechanical movement during treatment, so the patient should be instructed to maintain the same position throughout the treatment delivery. During treatment, there can be chances of random and systematic errors. So, we considered ± 3 mm tolerance value for random and systematic errors. In our study, none of the plans get dose more than 110% of the prescribed dose. The chances of getting secondary malignancy in pediatric patients are more, so one should take care of whole-body integral doses.

The study conducted by Schiopu *et al.* studied the toxicity or early and late side effects and tumor control probability in central nervous system (CNS) carcinoma patients on helical tomotherapy. The common symptoms were neurotoxicity, dizziness, loss of appetite, and nausea. The survival for 3–5 years was 80%–70% with one patient of secondary malignancy [115]. In another study, it was reported that six children and six adults treated with helical tomotherapy for CSI got severe hematological toxicities because of low dose exposure to large volumes [116] [117]. In HIMRT, optic chiasm, brainstem, right and left lenses, right and left eyes, optic nerve, and parotid show less doses compared with 3DCRT and VMAT. There is minimal variation in the rectum, bladder, and femoral head doses in all techniques, whereas the bowel's volumetric dose is less in VMAT.

In our study, the main goal is to achieve high conformal dose distribution within target volumes, which simultaneously take care of OARs by accepting acceptable heterogeneous dose distribution. For phase 1, VMAT planning gives less TT (minutes) (9.72 ± 0.713) compared with HIMRT (17.77 ± 3.94). VMAT plans to give 8 minutes less TT compared with other techniques. In another study, it is mentioned that proton beam therapy can reduce OAR doses drastically compared with photon beam therapy because of the Bragg peak [118] [119]. The study conducted by Y. Sun *et al.* compared helical tomotherapy, VMAT, and IMRT for medulloblastoma patients, which concluded that helical tomotherapy offers better outcomes for target homogeneity, conformity, and OAR sparing when compared with VMAT or IMRT [120]. Because of helical treatment and smaller field width, HIMRT and H3DCRT take longer TT compared with VMAT, but OAR sparing is more in HIMRT. There are few studies on the comparison of techniques for CSI patients with small sample sizes.

In our study, we have taken 20 sample sizes and generated 120 treatment plans (for phase 1 60 plans and phase 2 60 plans). The present study on the comparison of HIMRT, H3DCRT, and VMAT for CSI is significant. From Fig. 4.1, the dosimetric comparison shows better CI, HI, and HT in all plans. In VMAT planning, doses at junctions of the arc are automatically calculated during optimization. CI is best achieved in HIMRT, followed by H3DCRT and VMAT. There is not much variation in HT, and it shows almost the same results for all techniques. From Fig. 4.2 for Boost-GTV and PTV-Brain, V95% is best achieved by H3DCRT followed by

HIMRT and VMAT. PTV-Spine shows 95% values with very little difference. For PTV-Spine, target volume HIMRT (99.70) shows high coverage with a 95% isodose curve of the prescribed dose, followed by H3DCRT (99.42) and VMAT (97.69). From [Fig. 4.5](#), the isodose distribution shows good coverage with 95% of the prescribed for all techniques, but VMAT plans show more spillage compared with other techniques. V107% values for all techniques are also evaluated, and they are within tolerance. One should take care of all the dosimetric parameters to get conformal, uniform, and homogeneous dose distribution and OAR sparing and reduce the chances of getting secondary malignancies and for the patient's long life expectancy and better clinical outcomes. The study findings are consistent with previous reports by Lee et al., Seppala et al., Sharma et al., Zong Wen et al., and Sun et al., who have also quantified superior conformity with helical base treatment planning techniques. Planning parameters such as modulation factors, pitch, field width, contouring, and sample size can affect the results with previous data. It is very important to evaluate the treatment plans in terms of CI, HI, HT, and doses to OARs so that there will be the best optimized plan.

4.4 CONCLUSION

This study concluded that for CSI, advanced treatment planning techniques such as HIMRT, H3DCRT, and VMAT show good target coverage. HIMRT shows the best conformal, homogeneous dose distribution and better OAR sparing. V95% is best achieved in HIMRT, and there are no junctions, so it can treat up to 135 cm of target length without hot and cold spot regions in the target area. Among different techniques, the HIMRT treatment planning technique is found to be one of the best for CSI patients as compared to H3DCRT and VMAT.

HIMRT treatment planning shows better CI and HI than the rest of the techniques. The volumetric doses of critical organs are reduced in the HIMRT technique so it reduces the adverse and late effects of radiations on patients. In HIMRT, we can treat up to 135 cm long target length with one plan and without any junction (hot or cold spot), whereas in VMAT plans if the target length is more than ≥ 40 cm, then the plan needs more than one isocenter location.

So, practically HIMRT gives better results in terms of hot and cold spots and also patient setup is easy compared with VMAT plans. To achieve the best optimized plan, it is equally important to choose the best suited algorithm for dose calculation with precisional accuracy. For the best results of CSI, one must address all dosimetric parameters.

OB-2

**Helical Tomotherapy Delivery Analysis: A Successful Solution
towards CSI Patients' Individualized Quality Assurance**

4.5 RESULT

In the present study comparison of TPS planned, measured and reconstructed absolute point dose 2D gamma and 3D gamma, D98% and D2% of target volumes of ten non-CSI patients has been tabulated in [Table 4.4](#). For all the ten non-CSI plans, variation between TPS calculated dose and ion chamber measured point dose with cheese phantom is with $\pm 1\%$ of agreement.

Table 4.4. Ten Non-CSI patient Comparison of absolute dose measurement on cheese phantom, 2DY and 3DY, Dose received by 98% of target area (D_{98%}) and Dose received by 2% of target volume (D_{2%}) for ionization chamber measured dose, TPS planned fluence and reconstructed dose from leaf open time sinograms (LOTS).

No of patients	Diagnosis	Absolute dose on cheese phantom			Gamma value TPS vs		TPS calculated dose		Reconstructed dose		% variation between TPS calculated dose and recon dose	
No. of patients	Site	TPS DOSE (Greys)	CALCULATED DOSE (Greys)	Dose reco from LOTS	PTW detected array 2D%	reconstructed by LOTS 3D%	D98% _PT_V	D2% _PT_V	D98% _PTV	D2% _PT_V	D98% _PT_V	D2% _PT_V
1	Buccal Mucosa	1.13	1.139	1.137	100	99.1	0.47	0.8	0.46	0.76	-0.02	-0.05
2	Tongue	1.36	1.36	1.38	99.7	98.7	0.35	0.81	0.45	0.77	0.29	-0.05
3	Left Breast	1.96	1.959	1.955	99.2	98.5	0.52	0.77	0.32	0.72	-0.38	-0.06
4	Rectum	1.89	1.9	1.92	99.8	98.3	0.79	0.97	0.78	0.91	-0.01	-0.06
5	Esophagus	1.59	1.58	1.59	99.7	99.4	0.61	0.94	0.73	0.92	0.20	-0.02
6	right Breast	1.35	1.34	1.33	99.3	98.6	0.41	0.84	0.31	0.88	-0.24	0.05
7	cervix	1.66	1.661	1.69	100	100	0.64	1.19	0.6	1.08	-0.06	-0.09
8	prostate	1.58	1.575	1.57	99.8	98.7	0.43	1.1	0.49	1.04	0.14	-0.05
9	maxilla	1.61	1.613	1.62	99.4	97.5	0.46	0.78	0.52	0.73	0.13	-0.06
10	GBS	1.36	1.362	1.369	99.7	98.5	0.52	0.78	0.42	0.72	-0.19	-0.08

For six patients of non-CSI, variation between TPS calculated dose and reconstructed dose from leaf open time sinograms is within $\pm 1\%$ of agreement and four patients have variation with $\pm 2\%$ of agreement with overall average (SD) of 0.44%(0.03%). 2D γ for non-CSI patient is greater than 99.2% with average (SD) of 99.66% (0.21%) for planar dose distribution when compared to TPS calculated fluence and PTW 1500 detector array measured fluence. For all non-CSI patients 3D γ is greater than 97.5% with overall average (SD) of 98.73% (0.42%) for volumetric dose compared to TPS calculated dose and Leaf open time reconstructed dose. For non-CSI patient D98%

and D2% variation is find out between TPS and reconstructed dose. D98% for target max (average $\pm$ SD) is 0.38% (0.02% $\pm$ 0.12%) and D2% for target maximum (average $\pm$ SD) is 0.1% (0.05% $\pm$ 0.02%) For 20 CSI patients point dosimetry has been done at 4 locations like Brain, neck, thorax and abdomen. All the measured dose data is shown in Table 4.5. The comparison has been done with TPS calculated dose and ionization chamber calculated dose with maximum (average $\pm$ SD) of 2.98% (0.46% $\pm$ 1.61%). For CSI patient pre-treatment verification has been done only for PTV-Brian. For CSI patients shows 2D γ (3% @ 3mm) with maximum (average $\pm$ SD) is 100% (99.8% $\pm$ 0.0%) as compared to 3D γ of 97% (89.45% $\pm$ 0.0%) from LOTS reconstruction doses.

Table 4.5. Comparison of TPS planned dose and measured point dose with ionization chamber at four sites lie Brain, neck, thorax and abdomen or ten CSI patients.

ABSOLUTE DOSE ON CHEESE PHANTOM			% VARIATION	ABSOLUTE DOSE ON CHEESE PHANTOM			% VARIATION
SITES	PT:1			SITES	PT:11		
	TPS DOSE (Greys)	CALCULATED DOSE (Greys)			TPS DOSE (Greys)	CALCULATED DOSE (Greys)	
BRAIN	1.43	1.43	0.00	BRAIN	1.27	1.28	0.79
NECK	1.27	1.25	-1.57	NECK	1.32	1.31	-0.76
THORAX	1.35	1.33	-1.48	THORAX	1.47	1.49	1.36
ABODOMEN	1.73	1.78	2.89	ABODOMEN	1.67	1.7	1.80
	PT:2				PT:12		
	TPS DOSE (Greys)	CALCULATED DOSE (Greys)			TPS DOSE (Greys)	CALCULATED DOSE (Greys)	
BRAIN	1.53	1.56	1.96	BRAIN	1.51	1.51	0.00
NECK	1.32	1.33	0.76	NECK	1.29	1.3	0.78
THORAX	1.6	1.62	1.25	THORAX	1.67	1.65	-1.20
ABODOMEN	1.7	1.72	1.18	ABODOMEN	1.8	1.85	2.78
	PT:3				PT:13		
	TPS DOSE (Greys)	CALCULATED DOSE (Greys)			TPS DOSE (Greys)	CALCULATED DOSE (Greys)	
BRAIN	1.51	1.54	1.99	BRAIN	1.48	1.48	0.00
NECK	1.4	1.41	0.71	NECK	1.5	1.52	1.33
THORAX	1.63	1.65	1.23	THORAX	1.58	1.56	-1.27
ABODOMEN	1.7	1.74	2.35	ABODOMEN	1.62	1.65	1.85
	PT:4				PT:14		
	TPS DOSE (Greys)	CALCULATED DOSE (Greys)			TPS DOSE (Greys)	CALCULATED DOSE (Greys)	
BRAIN	1.48	1.49	0.68	BRAIN	1.29	1.29	0.00
NECK	1.26	1.24	-1.59	NECK	1.45	1.47	1.38
THORAX	1.33	1.35	1.50	THORAX	1.5	1.48	-1.33
ABODOMEN	1.73	1.69	-2.31	ABODOMEN	1.62	1.65	1.85
	PT:5				PT:15		
	TPS DOSE (Greys)	CALCULATED DOSE (Greys)			TPS DOSE (Greys)	CALCULATED DOSE (Greys)	
BRAIN	1.45	1.44	-0.69	BRAIN	1.4	1.41	0.71
NECK	1.32	1.34	1.52	NECK	1.65	1.67	1.21
THORAX	1.57	1.61	2.55	THORAX	1.4	1.39	-0.71
ABODOMEN	1.76	1.74	-1.14	ABODOMEN	1.83	1.87	2.19
	PT:6				PT:16		
	TPS DOSE (Greys)	CALCULATED DOSE (Greys)			TPS DOSE (Greys)	CALCULATED DOSE (Greys)	
BRAIN	1.59	1.57	-1.26	BRAIN	1.4	1.41	0.71
NECK	1.43	1.47	2.80	NECK	1.54	1.54	0.00
THORAX	1.67	1.65	-1.20	THORAX	1.26	1.25	-0.79

ABODOMEN	1.72	1.7	-1.16	ABODOMEN	1.7	1.73	1.76
	PT:7				PT:17		
	TPS DOSE (Greys)	CALCULATED DOSE (Greys)			TPS DOSE (Greys)	CALCULATED DOSE (Greys)	
BRAIN	1.39	1.37	-1.44	BRAIN	1.29	1.3	0.78
NECK	1.26	1.26	0.00	NECK	1.4	1.39	-0.71
THORAX	1.34	1.33	-0.75	THORAX	1.5	1.54	2.67
ABODOMEN	1.7	1.68	-1.18	ABODOMEN	1.67	1.69	1.20
	PT:8				PT:18		
	TPS DOSE (Greys)	CALCULATED DOSE (Greys)			TPS DOSE (Greys)	CALCULATED DOSE (Greys)	
BRAIN	1.44	1.43	-0.69	BRAIN	1.34	1.35	0.75
NECK	1.29	1.28	-0.78	NECK	1.57	1.59	1.27
THORAX	1.55	1.57	1.29	THORAX	1.7	1.68	-1.18
ABODOMEN	1.84	1.81	-1.63	ABODOMEN	1.54	1.57	1.95
	PT:9				PT:19		
	TPS DOSE (Greys)	CALCULATED DOSE (Greys)			TPS DOSE (Greys)	CALCULATED DOSE (Greys)	
BRAIN	1.48	1.48	0.00	BRAIN	1.25	1.24	-0.80
NECK	1.28	1.27	-0.78	NECK	1.5	1.48	-1.33
THORAX	1.41	1.42	0.71	THORAX	1.49	1.47	-1.34
ABODOMEN	1.68	1.71	1.79	ABODOMEN	1.63	1.65	1.23
	PT:10				PT:20		
	TPS DOSE (Greys)	CALCULATED DOSE (Greys)			TPS DOSE (Greys)	CALCULATED DOSE (Greys)	
BRAIN	1.36	1.35	-0.74	BRAIN	1.43	1.44	0.70
NECK	1.5	1.51	0.67	NECK	1.3	1.32	1.54
THORAX	1.35	1.35	0.00	THORAX	1.67	1.69	1.20
ABODOMEN	1.67	1.7	1.80	ABODOMEN	1.54	1.58	2.60

From [Table 4.6](#) represented 3D γ of PTV-Brain and PTV-Spine resulted from TPS calculated dose distribution and reconstructed dose from LOTS. 3D γ for PTV-Brain maximum (average $\pm$ SD) is 99.00% (95.3% $\pm$ 6.36%) and for PTV-Spine 3D γ maximum (average $\pm$ SD) is 99.00% (89.7% $\pm$ 2.82%).

There is favourable agreement in TPS planned dose distribution and LOTS reconstructed dose distribution, considering 3mm, 3% criteria for gamma evaluation and isogamma levels greater than one has been shown in [Fig. 4.6\(a\)](#) for one of CSI patient and 3D gamma for PTV_Brain and PTV_Spine in [Fig. 4.6\(b\)](#), cumulative DVH of planned dose and reconstructed dose for organs at risk [Fig. 4.6\(c\)](#) and comparison between TPS planned dose Vs reconstructed dose $D_{98\%}$ and $D_{2\%}$ for PTV_Brain and PTV_Spine [Fig. 4.6\(d\)](#).

[Fig. 4.7\(a\)](#) represents of % variation $D_{98\%}$ PTV_Brain planned and reconstructed doses, [Fig. 4.7\(b\)](#) shows % variation $D_{2\%}$ for PTV_Brain, [Fig. 4.7\(c\)](#) shows % variation $D_{98\%}$ for PTV_Spine and [Fig. 4.7\(d\)](#) shows % variation $D_{2\%}$ for PTV_Spine. The average deviation for $D_{98\%}$ PTV_Brain and $D_{98\%}$ of PTV_Spine is 1.61 and 1.77 respectively. The average deviation for $D_{2\%}$ PTV_Brain and PTV_Spine is 1.11 and 2.41 respectively.

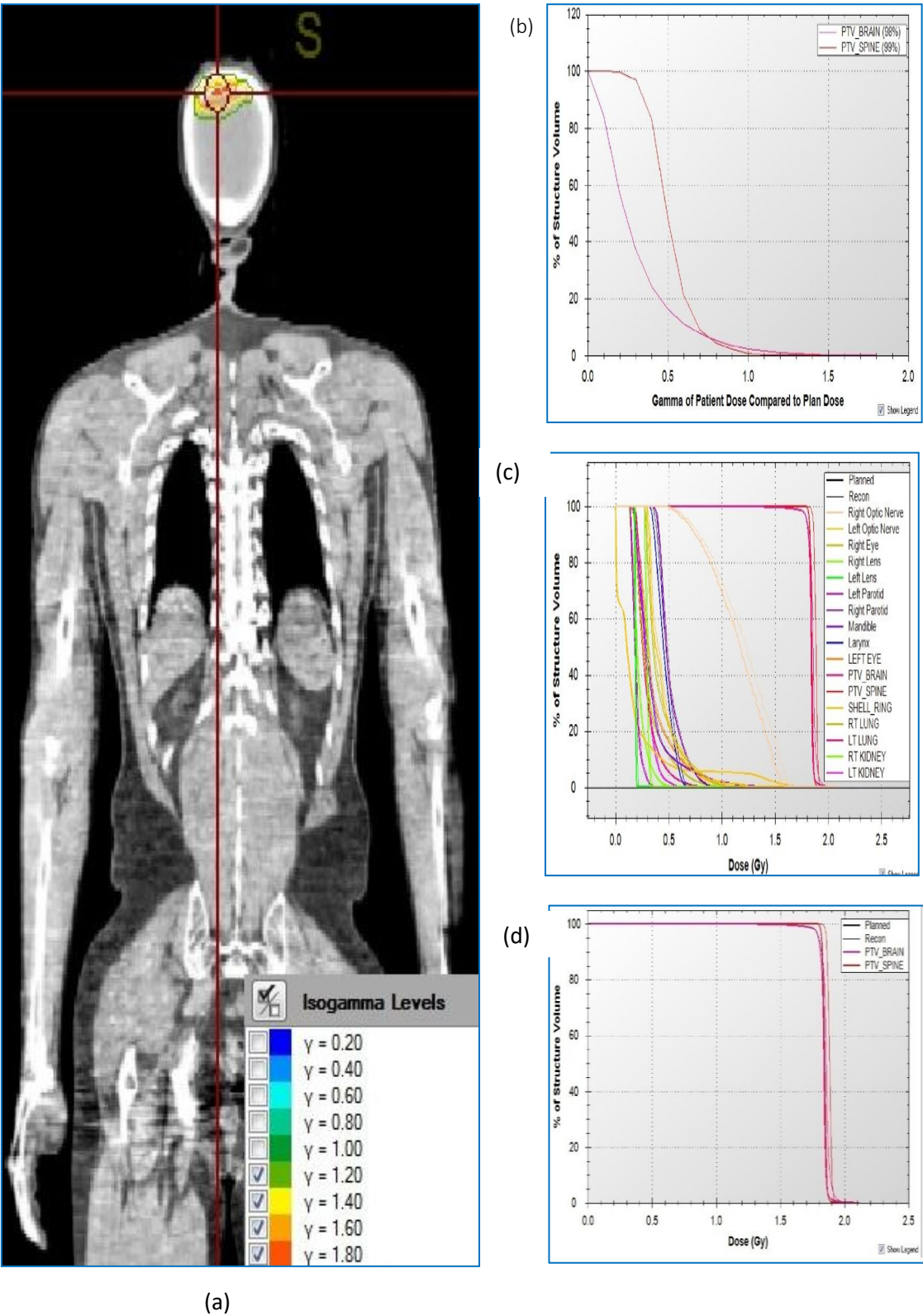
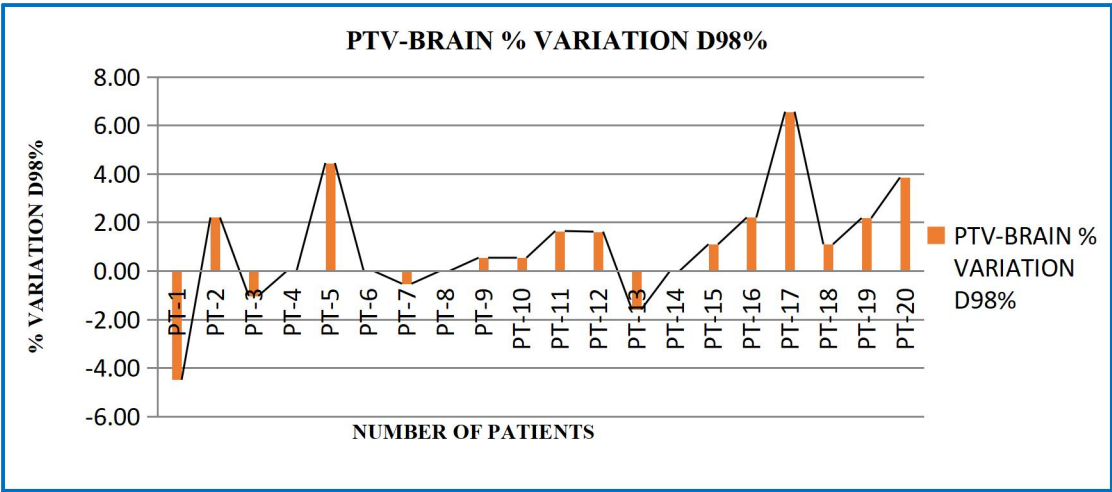


Fig. 4.6. (a) Coronal view of isogamma levels greater than one getting from planned dose and reconstructed dose through Leaf open time sinograms (LOTS) for one of the CSI patient. 3D gamma was analyzed with 3% dose difference (DD) and 3mm distance to agreement (DTA). **(b)** 3D gamma for PTV_Brain and PTV_Spine for one

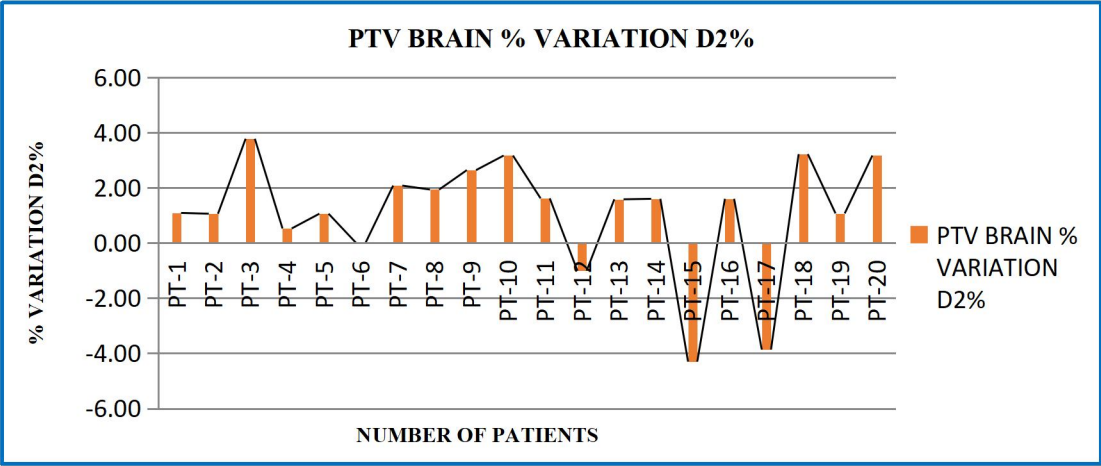
of CSI patient. (c) Cumulative DVH of planned dose and reconstructed dose for organs at risk. (d) Plot of cumulative dose volume histogram (DVH) of planned gamma and reconstructed gamma for PTV_Brain and PTV_Spine target volumes.

Table 4.6. Reconstructed 3D Y% from LOTS for PTV_Brain and PTV_Spine for 20 CSI patients.

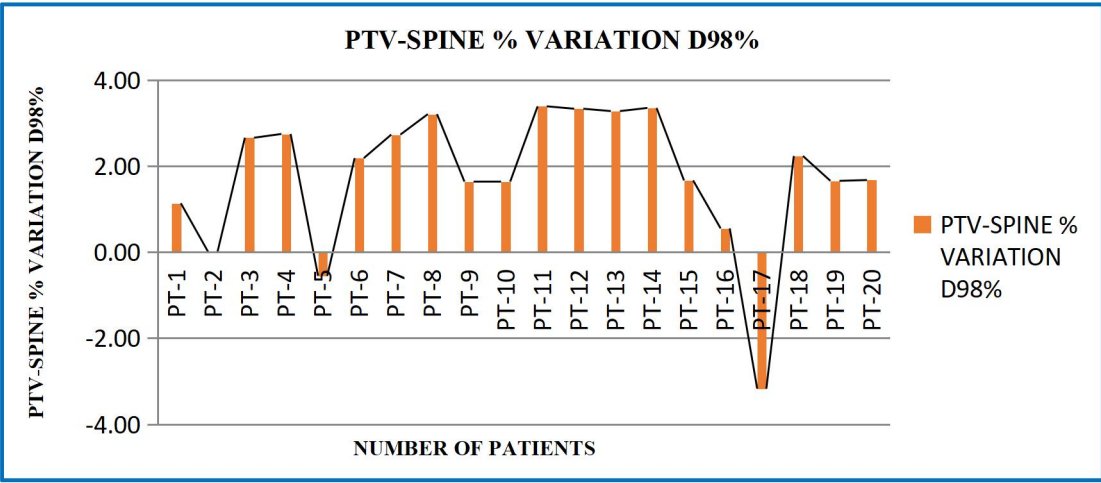
	3DY% from reconstructed LOTS									
SITE	PT:1	PT:2	PT:3	PT:4	PT:5	PT:6	PT:7	PT:8	PT:9	PT:10
PTV BRAIN	98	97	92	97	98	95	96	89	94	97
PTV SPINE	94	83	85	89	99	93	88	92	97	89
	PT:11	PT:12	PT:13	PT:14	PT:15	PT:16	PT:17	PT:18	PT:19	PT:20
PTV BRAIN	99	97	93	90	98	94	97	99	97	89
PTV SPINE	87	95	79	87	91	93	84	92	87	90



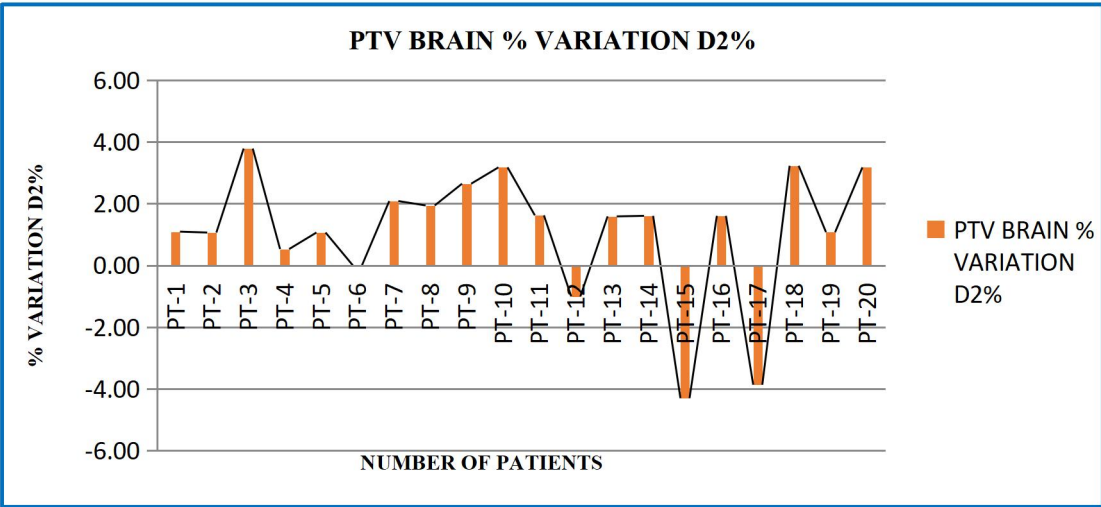
(a)



(b)



(c)



(d)

Fig. 4.7. (a) and (b) is percentage variation of TPS planned and delivery analysis reconstructed D98% and D2% of PTV_BRAIN target volume. (c) and (d) is percentage variation of TPS planned and delivery analysis reconstructed D98% and D2% of PTV_SPINE target volume

4.6 Discussion

This discussion assessed the feasibility and impact of Delivery analysis as a very important tool for patient specific QA. In our institute the standard protocol for patient specific quality assurance of craniospinal irradiation on Accuray Radixact X9 machine is to do point dosimetry at different locations like brain, neck, thorax and abdomen using AISL I ionization chamber with 0.053cc sensitive volume inserted inside standard imaging cheese phantom and 2D gamma index is calculated only for PTV brain tumor using PTW 1500 detector array and Octavius phantom. PTW 1500 detector array can measure fluence up to 25 cm length in a single procedure. There are various studies presented on absolute dose measurement, treatment planning and fluence measurement using various phantom and detector array for craniospinal irradiation [121] [122] [123] [124]. Deshpande et. al study dose reconstruction based on exit detector for helical tomotherapy has been done comparison of absolute dose was done for TPS calculated dose and ion chamber measure dose. Delivery quality analysis has been done for three CSI patients with exit detector DQA and ArcCHECK phantom [125]. PTV brain is chosen for the fluence verification due to complicated shape and nearby organs at risk. The practicality of 3D dose reconstruction from leaf open time sinograms on patient CT is present where various reconstruction algorithms are used for dose reconstruction in clinical practice. MVCT for patient specific quality assurance to calculate LOTs and reconstruct 3D dose distribution is studied by many authors [126] [127] [128] [129] [130]. For all non-CSI patients there is good agreement in absolute dose measurement ($\leq \pm 1\%$) and $2D\gamma$ ($>99.2\%$), $3D\gamma$ (97.5%) compared to planned dose, ion chamber measured dose in cheese phantom, PTW 1500 detector array measured fluence and, reconstructed dose from LOTs through Delivery analysis. The practicality of Delivery analysis, MVCT LOTs measurement of $3D\gamma$ is another method for PSQA of craniospinal irradiation patients. The practicality of MVCT LOTs craniospinal irradiation has be described as another approach for PSQA for craniospinal irradiation patients. The utility and authentication of this

method for craniospinal irradiation patient is very important because there is no direct method, suitable phantom and detector combination to measure delivered dose with accuracy of such a long treatment field because conventional QA phantoms are limited for long size target areas. The study done by Nasrallah et. al have done validation of calculation methods for MLC leaf open time in PSQA in tomotherapy material. They have compared signal recorded by in build detectors and another is signal recorded by optical sensor which are placed on MLC. Their result shows good agreement between these two methods [131]. In our retrospective study the maximum 3D γ for PTV Brain from LOTs is 99% where Minimum is 89.0% and for PTV Spine maximum 3D γ is 99.0% and minimum 3D γ is 79%. For PTV Brain 3D γ shows better results compared to PTV spine. We have repeated the procedure for same of patients to remove any error due to connectivity, but we got lesser results for PTV spine. The overall results for PTVs are satisfactory for PTV Brain and for PTV Spine are considered acceptable. To get better plan quality and accurate treatment delivery, we should take optimum field width, pitch values and modulation factor, Delivery analysis does not calculate differences between TPS planned and gantry angle delivery, treatment couch position and treatment field width. It only calculate visions between MLC-LOT to calculate dose difference to get better dose distribution and implementation of LOTs from MLC as patient specific quality assurance, treatment planning parameter like field width, pitch and modulation. Factor plays very important role. This method provides accurate and easy way for verification of fluence for craniospinal irradiation patients. The average deviation of D_{98%} is within 1.61% where average deviation of D_{2%} is within 1.11% for PTV_Brain and average deviation of D_{98%} is within 1.77% where average deviation of D_{2%} is within 2.41% for PTV_Spine. In Overall result PTV_Brain Coverage (D_{98%}) from LOTs reconstructed technique was within $\pm 4.57\%$ and for PTV_Spine Coverage (D_{98%}) was within $\pm 3.39\%$. The hot spot (D_{2%}) for PTV_Brain was within $\pm 3.78\%$ and for PTV_Spine is within $\pm 4.81\%$. The observed gamma values and dose variations are in the acceptable limit and can use daily for overall quality assurance. The implementation of efficient QA tools helped to avoid potential radiation overdose to organs at risk (OARs) and confirmed the precision of treatment for the entire craniospinal axis. The method also provided feedback for improving patient setup and beam delivery techniques, optimizing the overall therapeutic outcomes. Advantages of delivery analysis are early

detection of delivery inaccuracies, increased confidence in treatment accuracy and allows adjustments during the treatment process, which is vital for complex treatments like CSI.

4.7 Conclusion

The use of delivery analysis as part of patient-specific QA in Helical Tomotherapy is a highly effective way to ensure the treatment of CSI patients is accurate and safe. Patient specific quality assurance with MLC-LOTS is accurate, easy and user friendly method for all types of patients. This is constructive and systematic method for patient specific quality assurance for long tumor size like craniospinal irradiation patients treated in helical tomotherapy. The planning parameters like field width values, pitch value and modulation factor value plays very important role in making optimized plan in terms of required multi leaf collimator leaf opening time. Optimized plan gives better dose distribution and good agreement of treatment plan delivery for patient quality assurance. The integration of this QA technique into clinical practice can significantly enhance the effectiveness of radiation therapy for CSI patients.

OB-3

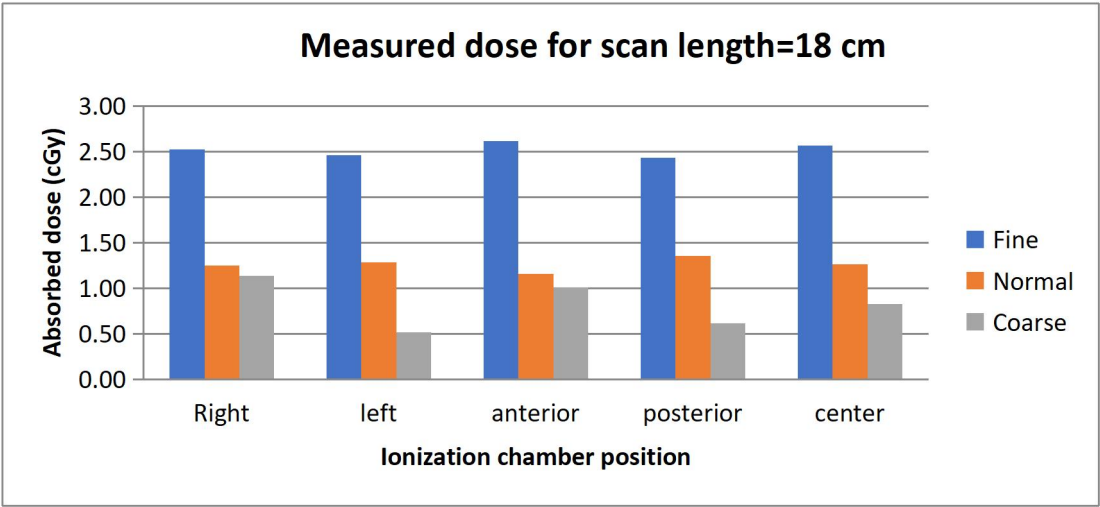
Evaluating the Megavoltage Computed Tomography (MVCT)
Weighted Computed Tomography Dose Index (CTDIw)

4.8 RESULTS

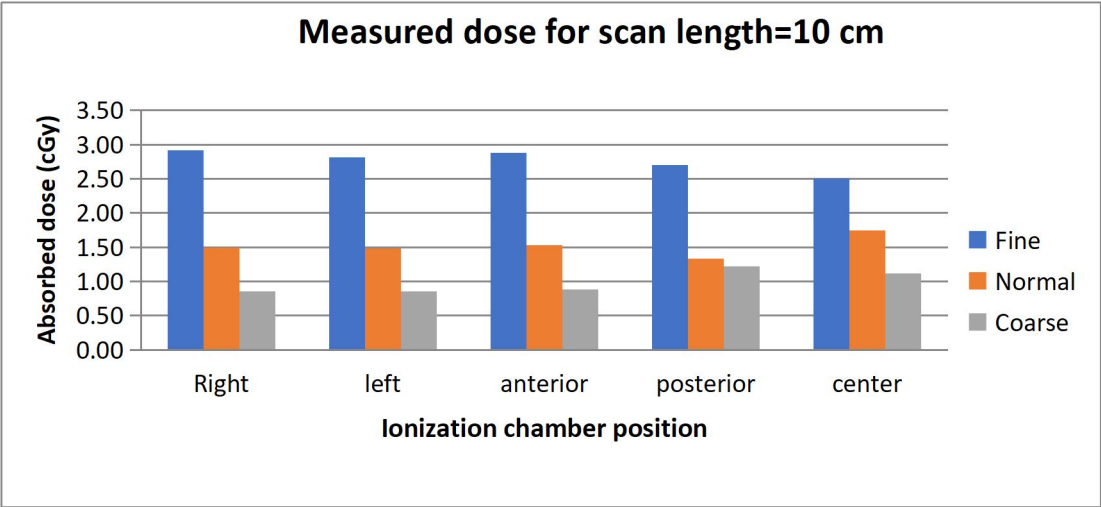
Table 4.7. Calculated values of doses at right, left, Anterior, Posterior, center of cheese phantom, CTDIw (Weighted Computed Tomography Dose Index), CTDIvol (Volume Computed Tomography Dose Index) and DLP (Dose Length Product) in cheese phantom for scan lengths of 18cm, 10cm, and 0.7cm with fine, normal and coarse pitch modes. Where D@R cGy represent dose at right side of cheese phantom, D@L cGy represent dose at left side of cheese phantom, D@A cGy represent dose at anterior side of cheese phantom, D@P cGy represent dose at posterior side of cheese phantom, D@C cGy represent dose at center of cheese phantom, Avg. Dp cGy represent average dose at periphery of cheese phantom.

Scan length (Cm)	Pitch	<u>D@R</u> cGy	<u>D@L</u> cGy	<u>D@A</u> cGy	<u>D@P</u> cGy	<u>D@C</u> cGy	Avg. Dp cGy	CTDIw cGy	CTDIvol cGy	DLP cGy
18	Fine=1mm	2.53	2.46	2.62	2.43	2.57	2.51	2.53	2.53	45.51
	Normal=2mm	1.25	1.28	1.16	1.36	1.26	1.26	1.26	0.63	22.73
	Coarse=3mm	1.14	0.52	1.01	0.61	0.83	0.82	0.82	0.27	14.80
10	Fine=1mm	2.91	2.81	2.88	2.71	2.50	2.83	2.72	2.72	27.19
	Normal=2mm	1.49	1.48	1.53	1.33	1.75	1.46	1.56	0.78	15.55
	Coarse=3mm	0.86	0.86	0.89	1.22	1.11	0.95	1.01	0.34	10.08
0.7	Fine=1mm	2.44	2.39	2.42	2.23	1.75	2.37	2.16	2.16	1.51
	Normal=2mm	1.11	1.33	1.17	1.24	0.99	1.21	1.14	0.57	0.80
	Coarse=3mm	0.53	1.19	0.65	0.90	0.69	0.82	0.77	0.26	0.54

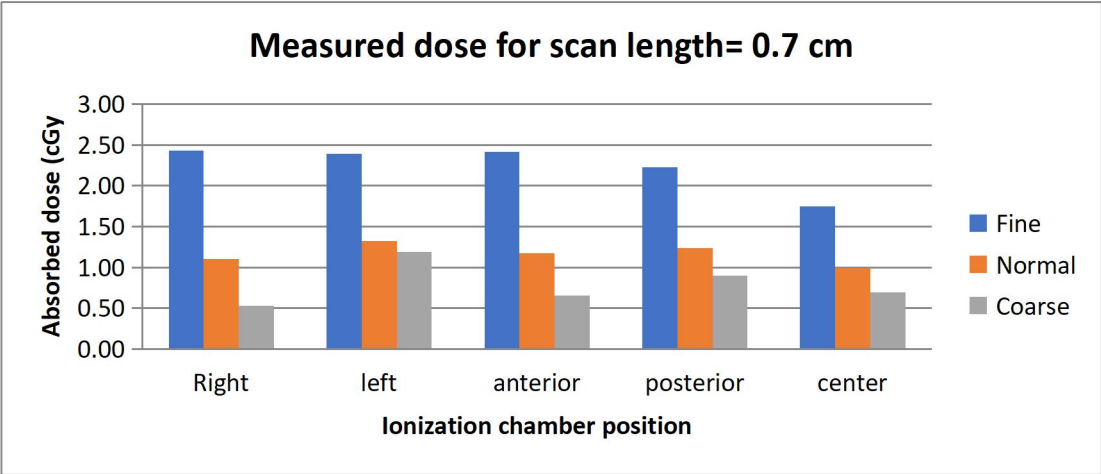
From [Table 4.7](#) it shows that CTDIw and CTDIvol are highest in fine mode for 18cm, 10cm, and 0.7cm scan lengths. For scan length 7mm, the tolerance values for CTDIw are 3Gy, 2Gy and 1Gy for fine, normal and coarse modes. Our finding shows that for 7mm calculated doses are 2.16 cGy, 1.14cGy and 0.77 cGy for fine, normal and coarse modes accordingly.



(a)



(b)



(c)

Fig. 4.8. Graphical representation of absorbed dose for fine, normal and coarse mode at right, left, anterior, posterior and center of Cheese phantom for scan length of 18 cm in figure “a”, 10 cm in figure “b”, and 0.7 cm in figure “c”.

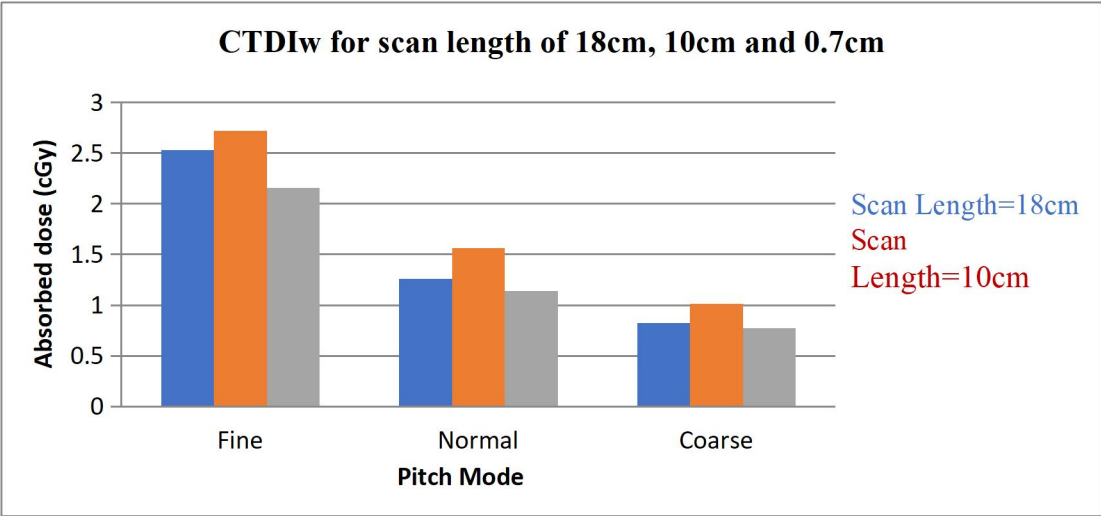


Fig. 4.9. Graphical representation of CTDI_w (Weighted Computed Tomography Dose Index) for scan lengths of 18cm in figure, 10cm and 0.7cm in figure with fine, normal and coarse pitch modes.

From Fig. 4.8(a), 4.8(b) and 4.8(c), maximum dose is measured in fine mode for 18 cm, 10 cm and 0.7 cm scan length. From Fig. 4.9, it is resulted that CTDI_w calculated for 18cm, 10cm and 0.7cm is maximum for fine pitch mode.

4.9 DISCUSSION

This discussion explained the extra amount of delivered dose during MVCT taken during image guided radiation therapy on Accuray Radixact x9 linac and also compared the results with previous studies. It is well known fact that extra dose during MVCT imaging can cause an impact on patient's quality of life. The study of Jung et al used virtual water phantom with 30 cm diameter and ASL1 0.053 cc standard imaging ion chamber for 10.8 cm scan length with fine (1 cm), normal (2 mm) and coarse (3 mm) pitch mode. Their results show 2.69 cGy dose for fine mode, 1.3 cGy dose for normal mode and 0.85 cGy dose for coarse mode measured [132]. The study of Fast et al. used acrylic phantom with 33 cm diameter with PTW M31002 0.125 cc ion chamber. Their result shows 2.4 cGy dose for fine mode, 1.2 cGy dose for normal (2 mm) mode and 0.8 cGy dose for coarse (3 mm) mode [133]. Shah et al. did comparative study for acrylic and virtual water phantom with diameter of 20 cm and 30 cm, respectively. AISL 0.053 cc standard imaging ionization chamber was used for 18 cm scan length. The results show that with acrylic phantom, it is 2.21 cGy

dose for fine (1 mm) mode, 1.14 cGy dose for normal (2 mm) mode and 0.76 cGy dose for coarse (3 mm) mode. Measurements with virtual water phantom for normal (2 mm) mode were 1.06 cGy. Doses calculated with virtual water phantom are less compared to acrylic phantom [134]. The study Chen et al. used acrylic and water phantom for 9.6 cm scan length with various diameters. Their results show 2.33 cGy dose for fine (1 mm) mode, 1.17 cGy dose for normal (2 mm) mode and 0.78 cGy dose for coarse mode (3 mm) [135]. The study of Jean Pierse mege et al. used virtual water phantom with 30 cm diameter and AISL 0.053 standard imaging ion chamber for 10 cm scan length. Their results show 2.7 cGy dose for fine 1 mm pitch mode, 1.4 cGy dose for normal 2 mm mode and 1 cGy dose for coarse mode 3 mm [136]. In the present study, weighted computed tomography dose index has been calculated for Accuray Radixact X9 linac during MVCT imaging procedures. We have used virtual water cheese phantom with AISL1 0.053 cc standard imaging ion chamber. Measurements have been taken for 18 cm, 10 cm and 0.7 cm scan lengths in fine (1 mm), normal (2 mm) and coarse (3 mm) pitch mode. Our findings for 18 cm scan length CTDIW are 2.72 cGy, 1.56 cGy and 1.01 cGy for fine, normal and coarse pitch mode. Our results are nearly same to the previous studies. CTDIvol is highest for fine mode compared to other modes. Imaging is a tool for the patient setup verification and minimizes randomized errors. Repeated imaging increases the daily doses, which adds extra dose in the patient's total dose. Kupelian et. al. and langens et. al. research finding shows that MVCT in normal mode ranged 1 cGy to 1.5 cGy/scan. Scanning time is an important parameter for estimation of doses during MVCT. The measured CTDIW, are also consistent with previous studies. Therefore, we should be very careful in selecting mode of imaging and scan length to reduce extra exposure as well as long term effects.

4.10 Conclusion

In the image-guided radiotherapy technique, imaging can be taken more than once if required. CTDIW is maximum for fine pitch mode and lowest for coarse pitch mode. The dose received by the patient during imaging is highly depends upon the pitch, imaging site and length of scanning area. Depending upon pitch mode and repetition imaging procedure for helical treatment can increase the patient's total dose. Adequate knowledge about how to perform procedure with accuracy and without repetition

procedure can definitely reduce the unnecessary doses to patients during imaging. CTDIw is a good method for evaluation of doses received during imaging procedures.

OB-4

Quantitative Examination of Integral Doses and Skin Entry Exit Doses among Patients Received Craniospinal Irradiation Utilizing Various Radiation Treatment Delivery Approaches.

4.11 Results

From Table 4.8, for skin, Dmax (maximum dose) is highest in HIMRT (FFF) at 59.70 Gy (110.55%), Dmean is highest in H3DCRT (FFF) at 7.67Gy whereas VMAT(FF) plans show minimum Dmax 55.75 Gy and minimum Dmean 4.13 Gy. For skin_ring, Dmax is highest in H3DCRT at 50.90 Gy, and Dmean is high in H3DCRT at 5.23 Gy. The skin entry exit doses are highest in H3DCRT (FFF) 7.87Gy, and VMAT (FF) plans show minimum doses of 4.09Gy. The result shows that VMAT (FF) plans show minimum skin entry exit doses, whereas there is a minor difference in skin entry exit doses for HIMRT and H3DCRT treatment planning techniques. Dosimetric comparison of volumetric doses to Skin and Skin_ring (D_{max} , D_{mean} , D_{min} , $D_{80\%}$, $D_{50\%}$, $D_{30\%}$, $D_{10\%}$) , entry exit doses and p-values for HIMRT (FFF), H3DCRT (FFF) and VMAT (FF) treatment planning techniques. Where * represents repeated measure ANOVA Wilks’s Lambda Test and # represents Friedman’s ANOVA Test.

Table 4.8. Effect of HIMRT (FFF), H3DCRT (FFF) and VMAT (FF) treatment planning techniques on skin and skin-ring.

OARs	Dosimetric parameters	HIMRT (FFF)	H3DCRT (FFF)	VMAT (FF)	P- VALUES HIMRT VS. H3DCRT VS. VMAT
Skin	Dmax	59.70±1.74 1	58.59±2.334	55.75±2.573	0.000*
	Dmean	7.07±3.421	7.67±3.798	4.13±1.595	0.000 [#]
	Dmin	0.10±0.243	0.13±0.300	0.11±0.271	0.000 [#]
	D _{80%}	0.61±1.014	1.47±3.277	0.73±1.273	0.000 [#]
	D _{50%}	3.46±1.753	4.06±2.141	3.33±1.502	0.001 [#]
	D _{30%}	4.74±1.348	7.11±6.651	5.11±2.377	0.003 [#]
	D _{10%}	15.21±5.97 9	18.73±11.76 0	9.75±4.321	0.000*
	Entry & exit dose	7.07±.703	7.87±0.958	4.09±0.706	0.000*
Skin_ ring	Dmax	48.83±3.49 3	50.90±2.606	48.55±2.472	0.000*
	Dmean	4.62±2.253	5.23±3.055	4.33±2.128	0.000 [#]
	Dmin	0.10±0.246	0.12±0.300	0.03±0.091	0.000 [#]
	D _{80%}	0.50±0.828	0.6±1.050	0.35±0.752	0.000 [#]
	D _{50%}	2.36±1.352	2.75±1.512	2.12±1.226	0.000 [#]
	D _{30%}	4.46±3.879	4.92±4.905	3.81±2.426	0.000 [#]
	D _{10%}	9.61±2.793	9.99±3.270	10.40±6.791	0.573*

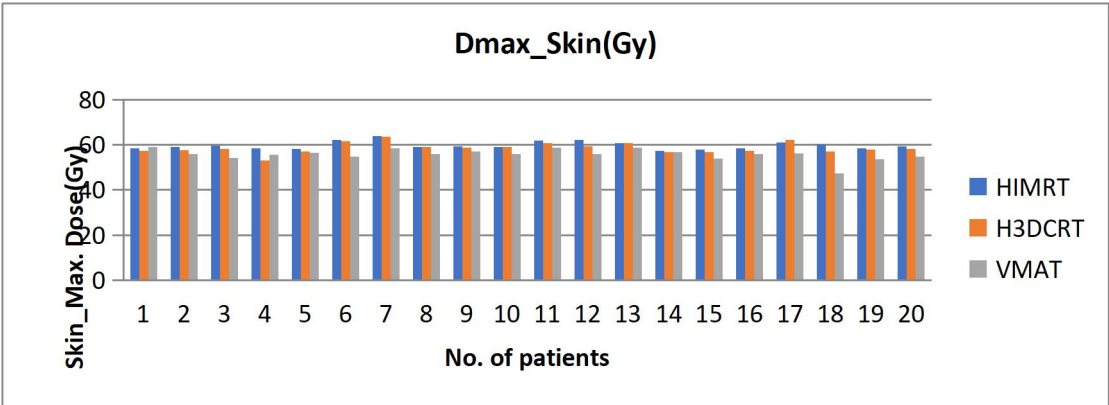


Fig. 5.0. Dosimetric comparison of skin maximum doses (Dmax) in HIMRT, H3DCRT and VMAT treatment planning techniques.

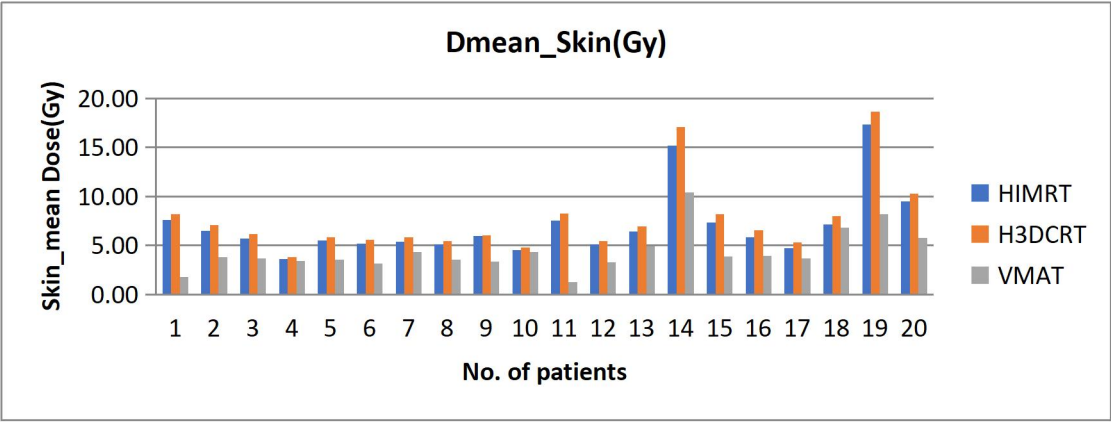


Fig. 5.1. Dosimetric comparison of skin mean doses (Dmean) in HIMRT, H3DCRT and VMAT treatment planning techniques.

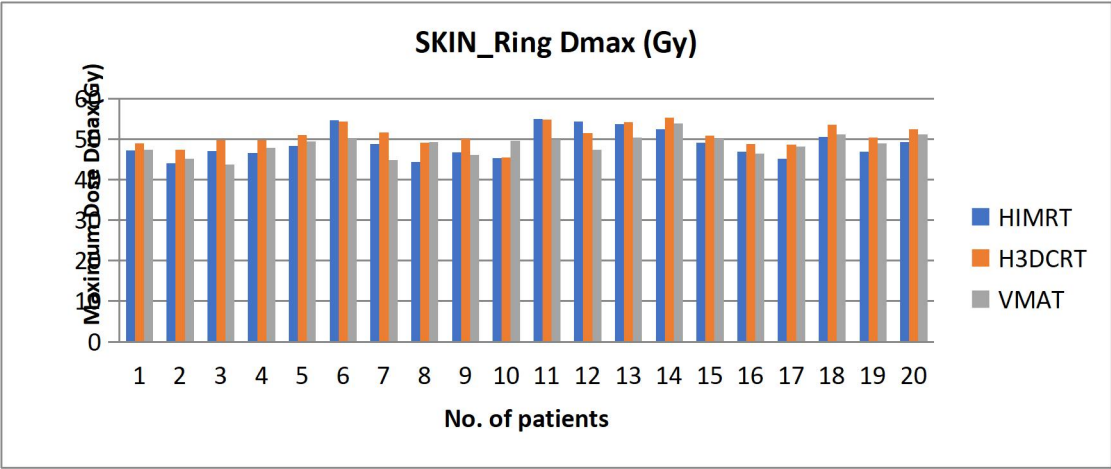


Fig. 5.2. Dosimetric comparison of skin_ring maximum doses (Dmax) in HIMRT, H3DCRT and VMAT treatment planning techniques.

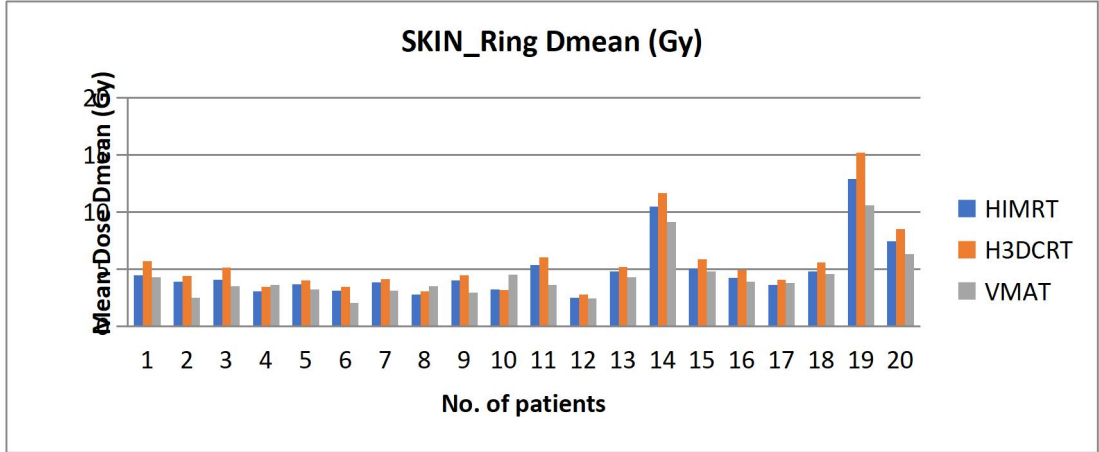


Fig. 5.3. Dosimetric comparison of skin_ring mean doses (Dmean) in HIMRT, H3DCRT and VMAT treatment planning techniques.

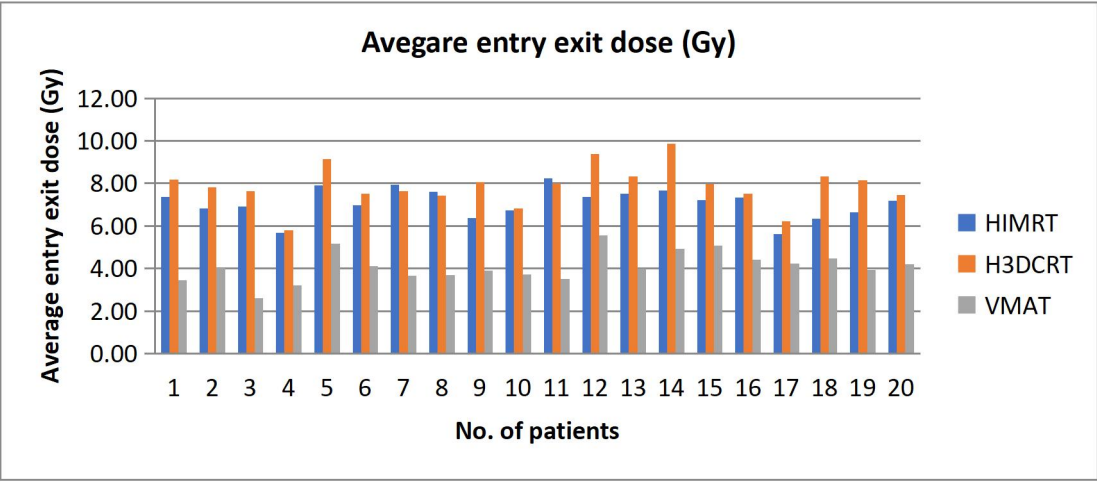


Fig. 5.4. Dosimetric comparison of skin average entry exit doses in HIMRT, H3DCRT and VMAT treatment planning techniques.

Table 4.9. Effect of HIMRT, H3DCRT and VMAT treatment planning techniques on integral doses in Phase-1 and Phase-2

Target Volume	Dosimetric parameters	HIMRT	H3DCRT	VMAT	P- VALUES
					HIMRT Vs. H3DCRT Vs. VMAT
PTV_Brain & PTV_Spine	ID_Phase_1	11.37±4.458	12.30±5.007	7.21±2.990	0.000 [#]
	ID_Phase_2	0.10±0.109	0.11±0.117	0.03±0.067	0.000 [#]

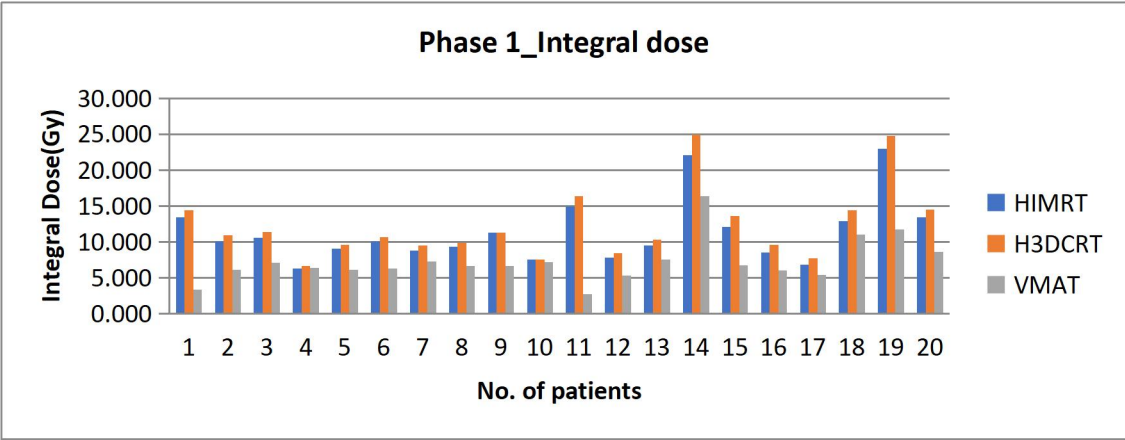


Fig. 5.5. Dosimetric comparison of integral doses for Phase-2 in HIMRT, H3DCRT, and VMAT treatment planning techniques.

From Fig. 5.0, dosimetric comparison of maximum doses (D_{max}) has been done for skin structure in HIMRT, 3DCRT and VMAT treatment planning. HIMRT and H3DCRT treatment plans showing high maximum doses, whereas minimum doses in VMAT treatment planning.

From Fig. 5.1, mean doses (D_{mean}) have been evaluated for skin in HIMRT, 3DCRT, and VMAT treatment planning techniques. Maximum D_{mean} is showing in HIMRT and H3DCRT, whereas VMAT plans show fewer mean doses.

From Fig. 5.2, maximum doses (D_{max}) have been compared for skin_ring structure in HIMRT, 3DCRT, and VMAT treatment planning techniques. Results show that H3DCRT plans show high D_{max} , and there is a minor difference in HIMRT and VMAT results.

From Fig. 5.3, dosimetric comparisons of mean doses (D_{mean}) have been made for skin_ring structure in HIMRT, 3DCRT, and VMAT treatment planning techniques. It was found that H3DCRT plans show highest D_{mean} . Whereas HIMRT and VMAT treatment plans are with less doses and approximately same results.

From Fig. 5.4, dosimetric comparisons of average entry exit doses (Gy) have been done in HIMRT, 3DCRT, and VMAT treatment planning techniques. Results showed that maximum average entry exit doses are in H3DCRT and then HIMRT treatment planning techniques. Whereas VMAT plans show minimum average entry-exit doses.

From Table 4.9, Integral doses for target volume in Phase-1 and Phase-2 are highest in H3DCRT and VMAT treatment plans, showing comparatively fewer doses. The difference in the results is due to the treatment planning technique, collimation, dose rate, gantry speed, dose calculation sequencing parameter, and algorithm. The differences were statistically significant with p value less than 0.005 (significance level). The p-value, HIMRT Vs. H3DCRT Vs. VMAT for Phase-1, was 0.000, and for Phase-2 was 0.000.

Comparative analysis of integral doses for Phase-1 and Phase-2 with p-values for PTV_Brain and PTV_Spine in HIMRT, H3DCRT and VMAT treatment planning techniques. Where # represents Friedman’s ANOVA Test.

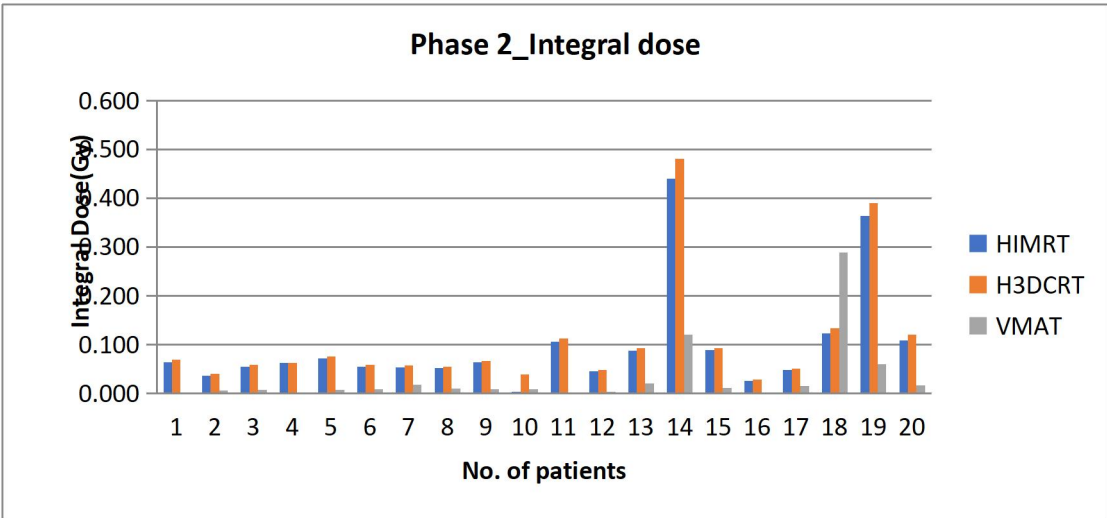


Fig. 5.6. Dosimetric comparison of integral doses for phase-2 in HIMRT, H3DCRT and VMAT treatment planning techniques.

From Fig. 5.5, dosimetric comparison of integral doses (ID) for Phase-1 treatment planning has been done in HIMRT, 3DCRT and VMAT treatment planning techniques. Treatment plans with H3DCRT and HIMRT techniques showing high integral doses. Whereas VMAT plan showing minimum integral doses.

From Fig. 5.6, a dosimetric comparison of integral doses (ID) for the boost plan has been made in HIMRT, 3DCRT, and VMAT treatment planning techniques. Maximum integral doses are shown in H3DCRT treatment plans and then HIMRT techniques. Whereas VMAT treatment plans showing minimum integral doses for all patients except patient number 14 and 18.

4.12 Discussion

This discussion mainly focused on comparison of skin entry-exit dose and integral dose in HIMRT, H3DCR and VMAT planning techniques. Skin entry exit doses strongly depend upon the type of treatment technique, beam energy, dose calculation algorithm, grid size, beam collimation, and modulation factor. These factors influence acute and late side effects, patient comfort and secondary malignancies. Helical treatment delivery in IMRT and 3DCRT mode showed higher skin entry-exit doses because of 360-degree beam entry-exit and lack of secondary collimators [137] [138]. Statistical analysis showed that p-values are significant for all treatment techniques. Integral doses are higher in helical treatment planning techniques compared to VMAT treatment planning techniques for PTV_Brain and PTV_Spine in Phase-1 and GTV_Boost in Phase-2. Skin OAR shows the highest Dmax in HIMRT and minimum Dmax in VMAT. Skin_ring at 3mm inner margin from skin showing highest Dmax in H3DCRT. For skin, OAR volumetric doses show better results in HIMRT. Particularly in CSI patients, HIMRT is the choice of treatment because of high conformity, homogenous dose distribution heterogeneity index, and simultaneous sparing of OAR's. There are few studies that compare integral doses for target volumes in CSI patients for HIMRT, 3DCRT, and Rapid arc treatment planning techniques [139] [140]. Goswami et al. 2020 studied the dosimetric comparison for CSI patients and compared integral doses delivered to OAR's and target volumes in Rapid arc, direct 3DCRT, and Direct IMRT treatment techniques. The results showed IDs are lower in rapid arc plans, and our study also showed lesser doses in VMAT plans compared to other treatment techniques; hence, the results of our research work have followed the same pattern as previous investigations [141]. Patel et al. studied the comparison of dosimetric parameters and integral doses in VMAT, HT, and 3DCRT for medulloblastoma cases of five children, and their results showed less ID in VMAT plans compared to other techniques [142]. The pattern of our results is also similar to prior research works. Our study findings show minimum skin entry exit doses and Integral doses in the VMAT treatment planning technique compared to HIMRT and H3DCRT treatment planning techniques. The study reported by Mohandass P. et al. and Mishra A. et al. is also in favor of VMAT for superior dose distribution with fewer entry-exit doses and fewer skin doses [143] [144]. Therefore, type of treatment

will affect dosimetric quality, patient safety and late side effects. One should consider all the parameters to get better treatment plans for better clinical results.

4.13 Conclusion

This study concludes the quantitative analysis of skin entry exit doses, volumetric doses of OARs, and target volumes integral doses. Statistical analysis showed skin entry-exit and integral doses are less in VMAT method (6MV FF) compared to other treatment planning techniques. For all treatment planning techniques, homogenous dose distribution was satisfactory. All dosimetric parameters are deciding factors for the choice of treatment.

CHAPTER – 5

SUMMARY AND CONCLUSION

In the present study, advanced treatment planning methods including HIMRT, H3DCRT, and VMAT exhibit good target coverage for CSI. HIMRT displays the most accurate conformal, improved OAR sparing and uniform dosage distribution. HIMRT can treat up to 135 cm of target length without producing hot and cold spot regions since it has no connections and achieves the best V95%. When compared to H3DCRT and VMAT, the HIMRT treatment planning strategy is one of the most effective methods for CSI patients. Better CI and HI are shown by HIMRT treatment planning than by the other methods. The HIMRT technique lessens the volumetric doses of vital organs, which lessens the negative and delayed effects of radiation on patients. With HIMRT, we can address a target length of up to 135 cm with a single plan and no junction (hot or cold spot); with VMAT plans, however, if the target length exceeds ≥ 40 cm, the plan requires several isocenter locations. For target volume PTV_Brain, Conformity index in different treatment techniques are mentioned (HIMRT = 1.02 ± 0.016 , H3DCRT = 1.04 ± 0.015 , VMAT = 1.11 ± 0.090), homogeneity indexes is (HIMRT = 0.73 ± 0.088 , H3DCRT = 0.39 ± 0.208 , VMAT = 0.43 ± 0.102), and Heterogeneity index is (HIMRT = 1.51 ± 0.013 , H3DCRT = 1.50 ± 0.017 , VMAT = 1.09 ± 0.018). For target volume PTV_Spine Conformity index in different treatment techniques are mentioned (HIMRT = 1.00 ± 0.004 , H3DCRT = 1.01 ± 0.013 , VMAT = 1.07 ± 0.039), homogeneity indexes is (HIMRT = 0.07 ± 0.043 , H3DCRT = 0.06 ± 0.070 , VMAT = 0.23 ± 0.183), and Heterogeneity index is (HIMRT = 1.10 ± 0.12 , H3DCRT = 1.11 ± 0.121 , VMAT = 1.06 ± 0.007). For target volume Boost_GTV Conformity index in different treatment techniques are mentioned (HIMRT = 1.035 ± 0.016 , H3DCRT = 1.04 ± 0.016 , VMAT = 1.08 ± 0.05), homogeneity indexes is (HIMRT = 0.80 ± 0.090 , H3DCRT = 0.44 ± 0.223 , VMAT = 0.56 ± 0.105), and Heterogeneity index is (HIMRT = 1.27 ± 0.006 , H3DCRT = 1.26 ± 0.009 , VMAT = 1.07 ± 0.009). Total Treatment time (minutes) for phase 1 in different techniques (HIMRT = 17.77 ± 3.974 , H3DCRT = 14.83 ± 3.750 , VMAT = 9.72 ± 0.713) and for phase 2 treatment time (HIMRT = 1.99 ± 0.306 , H3DCRT = 1.68 ± 0.326 , VMAT = 3.39 ± 0.918). All techniques, such as HIMRT, H3DCRT, and VMAT, give uniform and conformal target coverage, but HIMRT shows the best conformal and

homogeneous dose distribution and better OAR sparing. Therefore, in practice, HIMRT produces better hot and cold spot results and makes patient setup simpler than VMAT plans. In order to accomplish the optimal design, it is equally crucial to use the most appropriate algorithm for precisely calculating the dosage. Every dosimetric parameter needs to be taken into consideration for the optimum CSI outcomes.

Further, Helical Tomotherapy's use of delivery analysis as a patient-specific quality assurance tool is a very successful method of guaranteeing the precise and secure treatment of CSI patients. With MLC-LOTS, patient-specific quality assurance provides a precise, simple, and intuitive approach for all patient types. This is a positive and methodical approach to patient-specific quality assurance for patients with large tumors, such as those treated with helical tomotherapy after craniospinal irradiation. Making an optimal plan in terms of the necessary multi-leaf collimator leaf opening time requires careful consideration of planning characteristics such type of field width, pitch values, and modulation factor. For all ten non-CSI plans, variation between TPS calculated dose and ion chamber measured point dose with cheese phantom is with $\pm 1\%$ of agreement. 2D γ for non-CSI patient is greater than 99.2% with average (SD) of 99.66% (0.21%) for planar dose distribution when compared to TPS calculated fluence and PTW 1500 detector array measured fluence. For CSI patients shows 2D γ (3% @ 3mm) with maximum (average $\pm$ SD) is 100% (99.8% $\pm$ 0.0%) as compared to 3D γ for PTV-Brain maximum (average $\pm$ SD) is 99.00% (95.3% $\pm$ 6.36%) and for PTV-Spine 3D γ maximum (average $\pm$ SD) is 99.00% (89.7% $\pm$ 2.82%). The percentage variation for $D_{98\%}$ in PTV_Brain and PTV_Spine maximum (average $\pm$ SD) is 4.57% (1.61% $\pm$ 0.39%) and 3.39% (1.77% $\pm$ 0.38%) respectively. Percentage Variation for 2% is max (average $\pm$ SD) is 3.78% (1.11% $\pm$ 1.47%) and 4.81% (2.41% $\pm$ 1.37%) for PTV_Brain and PTV_Spine respectively. For patient quality assurance, an optimized plan results in better dosage distribution and good agreement of treatment plan delivery. Radiation therapy for CSI patients can be considerably more effective when this QA method is incorporated into clinical practice.

Further, imaging might be taken more than once in the image-guided radiation procedure. The coarse pitch mode has the lowest CTDI_w, whereas the fine pitch mode

has the most. The pitch, imaging site, and scanning area length all have a significant effect on patient dose receives during imaging. CTDI_w, CTDI_{vol}, and DLP have been calculated with cheese phantom using A1SL1 ion chamber. CTDI_w for 0.7 cm is 2.16 cGy, 1.14 cGy and 0.77 cGy for fine normal and coarse modes, respectively. The patient's overall dosage may rise based on the pitch mode and repeat imaging technique used for helical treatment. A sufficient understanding of how to carry out the process precisely and without repeat will undoubtedly cut down on the number of unwanted dosages given to patients during imaging. A useful technique for assessing the dosages received during imaging techniques is CTDI_w.

Further, quantitative evaluation of skin entry exit doses, OAR volumetric doses, and target volume integral dose is calculated in this work. Statistical research revealed that VMAT treatment planning strategies (6MV FF) had lower skin entry and exit doses, integral doses than helical FFF type of treatment planning techniques. Different dosimetric parameters like Max., Min, volumetric doses (D80%, D50%, D30%, and D10%) have been quantifiable for skin and skin_ring. For PTV-Brain and PTV-Spine, integral doses are quantifiable considering at least V95% (target coverage by 95% of the prescribed dose). Statistical data was analysed with SPS software version 22. Mean doses of skin entry and exit is [HIMRT (FFF)= 7.07 ± 0.703 , H3DCRT (FFF) = 7.87 ± 0.958 VMAT (FF)= 4.09 ± 0.706]. During first phase mean integral dose in PTV_Brain, PTV_Spine was [HIMRT (FFF)= 11.37 ± 4.458 , H3DCRT (FFF)= 12.30 ± 5.00 , VMAT (FF)= 7.21 ± 2.990] and in second phase mean integral doses for GTV_Boost was [HIMRT (FFF)= 0.10 ± 0.10 H3DCRT (FFF) = 0.11 ± 0.117 VMAT (FF)= 0.03 ± 0.067]. Study concludes that entry exit doses and integral doses were found to be max. in H3DCRT (FFF) and then HIMRT (FFF) and VMAT (FF) plans having min. doses. A homogeneous dosage distribution was suitable for every treatment planning technique. When choosing a treatment, all dosimetric characteristics are decisive.

The study provides a robust dosimetric comparison of HIMRT, H3DCRT and VMAT treatment planning techniques for Craniospinal Irradiation (CSI), which helps to select most suitable treatment modality in case of CSI patients. The productive implementation of Delivery analysis for verifying pre treatment quality assurance.

These results can be used as reference for future research work, protocol formation and planning optimization.

The study mainly focused on dosimetric parameters whereas clinical parameters such as survival, long term toxicity were not analysed and integral dose, skin doses and imaging doses were limited to specific protocol and may differ for other prescribed doses and imaging schedules.

5.1. Future Scope

(1) Photon beam 6MV FF & FFF is used for treatment planning and delivery while other treatment planning techniques like proton therapy, carbon ion therapy can be further explored for CSI.

(2) This work can be extended by increasing the sample size and larger multicenter patient's cohorts to obtain more precise and statistically robust outcomes.

(3) Adaptive radiotherapy and MRI-guided radiotherapy can be utilized to deliver precise and real time delivery in CSI patients.

(4) Assessment of secondary long term malignancies.

Taking all these factors into consideration, future research can create new opportunities in this field to investigate application of advanced treatment planning techniques for CSI patients.

CHAPTER-10

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LIST OF PUBLICATION

1. Publication

Original Article

Craniospinal irradiation for medulloblastoma tumors: Retrospective analysis of dosimetric comparison—An institutional study

ABSTRACT

Introduction: The comparative study of dosimetric parameters for craniospinal irradiation (CSI) in medulloblastoma cancer patients has been conducted using three different radiation treatment modalities, such as helical intensity-modulated radiation therapy (RT) (HIMRT), helical three-dimensional (3D) conformal RT (H3DCRT), and volumetric modulated arc therapy (VMAT). Evaluation based on dosimetric parameters has been performed to check the better clinical outcomes of recent treatment techniques over one another.

Materials and Methods: In this retrospective study, twenty patients have been taken who were suffering from average-risk medulloblastoma. For these patients, phase 1 and phase 2 treatment plans were generated with HIMRT, H3DCRT, and VMAT using Accuray Precision version 2.0.1.1 and Monaco version 5.51.10 treatment planning software (TPS). For dose calculation, the convolution superposition algorithm is used for HIMRT and H3DCRT and the Monte Carlo algorithm is used for VMAT.

Result: Homogeneity index (HI), conformity index (CI), heterogeneity index (HT), total treatment time (TT), and doses to organs at risk (OARs) have been calculated. Statistical analysis has been performed with a paired-samples test in Statistical Package for the Social Sciences (SPSS) software version 22. For target volume PTV_Brain, Conformity index in different treatment techniques are mentioned (HIMRT = 1.02 ± 0.016 , H3DCRT = 1.04 ± 0.015 , VMAT = 1.11 ± 0.090), homogeneity indexes is (HIMRT = 0.73 ± 0.068 , H3DCRT = 0.39 ± 0.208 , VMAT = 0.43 ± 0.102), and Heterogeneity index is (HIMRT = 1.51 ± 0.013 , H3DCRT = 1.50 ± 0.017 , VMAT = 1.09 ± 0.018). For target volume PTV_Spine Conformity index in different treatment techniques are mentioned (HIMRT = 1.00 ± 0.004 , H3DCRT = 1.01 ± 0.013 , VMAT = 1.07 ± 0.039), homogeneity indexes is (HIMRT = 0.07 ± 0.043 , H3DCRT = 0.06 ± 0.070 , VMAT = 0.23 ± 0.183), and Heterogeneity index is (HIMRT = 1.10 ± 0.12 , H3DCRT = 1.11 ± 0.121 , VMAT = 1.06 ± 0.007). For target volume Boost_GTV Conformity index in different treatment techniques are mentioned (HIMRT = 1.035 ± 0.016 , H3DCRT = 1.04 ± 0.016 , VMAT = 1.08 ± 0.05), homogeneity indexes is (HIMRT = 0.80 ± 0.090 , H3DCRT = 0.44 ± 0.223 , VMAT = 0.56 ± 0.105), and Heterogeneity index is (HIMRT = 1.27 ± 0.006 , H3DCRT = 1.26 ± 0.009 , VMAT = 1.07 ± 0.009). Total Treatment time (minutes) for phase 1 in different techniques (HIMRT = 17.77 ± 3.974 , H3DCRT = 14.83 ± 3.750 , VMAT = 9.72 ± 0.713) and for phase 2 treatment time (HIMRT = 1.99 ± 0.306 , H3DCRT = 1.68 ± 0.326 , VMAT = 3.39 ± 0.918). All techniques, such as HIMRT, H3DCRT, and VMAT, give a uniform and conformal target coverage, but HIMRT shows the best conformal and homogeneous dose distribution and better OAR sparing.

Conclusion: In this study, CSI patients treated with HIMRT showed better results in terms of conformity, homogeneity, and doses to organs at risk.

KEY WORDS: Conformity index, craniospinal irradiation, heterogeneity index and treatment planning systems, homogeneity index, medulloblastoma

INTRODUCTION

The most prevalent form of malignant brain tumor in children is medulloblastoma, which accounts for 18–20% of all cases of brain tumors. It is a cancerous, embryonal solid tumor of the cerebellum. However, it can happen at any age, with a peak incidence between 3 and 7 years old.^[1] The recommended

course of treatment for medulloblastoma is surgically removing the primary tumor, followed by

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RESEARCH

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Estimation of weighted computed tomography dose index (CTDI_w) in megavoltage computed tomography (MVCT)

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Abstract

Introduction Advanced technologies in radiation treatment deliveries require high accuracy and precision in setup before treatment to get accurate dose delivery for planned target volumes. During imaging procedures, patients are getting extra doses from kilovoltage computed tomography (KVCT) and megavoltage computed tomography (MVCT). Computed tomography dose index is an important dosimetric parameter to know the degree of radiation-induced side effects.

Aim The main aim of this study is to quantify the dose received by patients during MVCT imaging procedures, weighted computed tomography dose index (CTDI_w), volume computed tomography dose index (CTDI_{vol}) and dose length product (DLP).

Methods and materials This study has been performed on Radixact X9 LINAC machine with 6MV flattening filter-free (FFF) photon beam for treatment and imaging with 3.5 MeV average photon energy. CTDI_w and dose length product (DLP) have been calculated for different scanning lengths 18 cm, 10 cm and 0.7 cm with fine, normal and coarse modes with standard imaging A15L1 ion chamber, cheese phantom and tomoelectrometer.

Results CTDI_w, CTDI_{vol} and DLP have been calculated with cheese phantom using A15L1 ion chamber. CTDI_w for 0.7 cm is 2.16 cGy, 1.14 cGy and 0.77 cGy for fine normal and coarse modes, respectively.

Conclusion CTDI_w is a dosimetric index to know the dose levels at center and periphery of patient according to scan length. It gives an idea about how much additional dose is received by the patient during the imaging procedures. High pitch gives the lesser absorbed dose. DLP gives the knowledge about stochastic effects from radiation to patients after MVCT.

Keywords Weighted computed tomography dose index, Flattening filter-free, Megavoltage computed tomography, Kilovoltage computed tomography, Dose length product

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Quantitative Estimation of Integral Doses and Skin Entry Exit Doses during Different Radiation Treatment Delivery Techniques for Craniospinal Irradiation Patients

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ABSTRACT

Introduction: The present study includes a qualitative analysis of skin entry exit doses and Integral doses (ID) utilizing various treatment planning strategies.

Material and Methods: For this study, we have taken 20 patients suffering from medulloblastoma and planned for Craniospinal irradiation (CSI) with Helical Intensity Modulated radiation therapy HIMRT, Helical three dimensional conformal radiation therapy H3DCRT, and Volumetric modulated arc therapy VMAT treatment planning techniques on Accuray Radixact X9 and Elekta Synergy (Agility) linear accelerator.

Results: Various dosimetric parameters like D_{max} , D_{mean} , $D_{100\%}$, $D_{50\%}$, $D_{25\%}$, and $D_{10\%}$ have been calculated for skin and skin ring. Integral doses have been calculated for PTV-Brain and PTV-Spine, taking into consideration at least V95% (target coverage by 95% of the prescribed dose). Statistical analysis was done using SPSS software version 22. Mean skin entry and exit doses were [HIMRT=7.07±0.703, H3DCRT = 7.87±0.958 VMAT=4.09±0.706]. For Phase-1 mean integral dose for PTV_Brain and PTV_Spine was [HIMRT=11.37±4.458, H3DCRT=12.30±5.00, VMAT=7.21±2.990] and Phase-2 mean integral doses for GTV_Boost was [HIMRT=0.10±0.10 H3DCRT = 0.11±0.117 VMAT=0.03±0.067]. Skin entry exit doses and integral doses were observed to be highest in H3DCRT and then HIMRT. Meanwhile, VMAT plans show minimum entry exit doses and integral doses for Phase 1 and Phase 2.

Conclusion: This study concludes that VMAT treatment planning techniques showing less skin entry exit doses and integral doses compared with helical treatment planning techniques. Taking care of these factors can give better clinical outcomes in terms of less late side effects.

► Please cite this article as:

Devi R, Basandrai D, Passi K. Quantitative Estimation of Integral Doses and Skin Entry Exit Doses during Different Radiation Treatment Delivery Techniques for Craniospinal Irradiation Patients. Iran J Med Phys 2024; 21: 147-153. 10.22038/IJMP.2023.71025.2254.

Introduction

Arc-based radiation treatment deliveries include helical intensity modulated radiation therapy [HIMRT], Helical three dimensional conformal radiation therapy [H3DCRT], and Volumetric modulated arc therapy [VMAT]. Advancement technologies have enhanced treatment delivery and ensured the target coverage with prescribed doses while simultaneously reducing volumetric doses to Organs at risk [OAR]. However, during helical treatment delivery, through full 360-gantry rotation, there is the possibility that a large volume of patients will get low doses, too. Radio biologically low doses cause cell injury, which can result in late side effects [1]. During treatment planning, the skin is considered a type of critical organ that is at risk if it gets out of tolerance doses. Integrative doses to Planning Target Volume (PTV) and Organs at Risk (OAR) have been delivered during treatment delivery. Patients with medulloblastoma were treated using two-dimensional

(2D) junction techniques in the prone position and bilateral fields to the whole brain with required collimator rotations and one or more anterior fields to cover the spinal cord. Earlier 2D techniques get more skin doses, integral doses, and entry and exit doses. Developments in treatment delivery and treatment planning techniques currently make it feasible to reduce volumetric skin doses through the optimization of treatment plans. Nowadays, advanced techniques like Intensity intensity-modulated radiation Therapy (IMRT), Tomotherapy, and Volumetric Modulated Arc Therapy (VMAT) are available, which help in reducing doses to organs at risk and simultaneously conformal and homogenous dose distribution to the target volumes. These techniques use varying dose rates, small multileaf collimator sizes at the isocenter, beam energy, gantry speed, and algorithm [2,3] The amount of dose received by OAR and cells that come in the path of the

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Retrospective study of random and systematic errors in Head and Neck cancer Patients with Image guided Helical Intensity Modulated Radiation Therapy

Rama Devi^{1,2}, Deepak Basandrai^{1*}, Kamlesh Passi², Navneet kaur², Naveen Kanda², Ishu Sharma², Mridul Anand², Vikram Singh² and Munish Kumar².

¹Department of Physics, School of Physical Sciences and Chemical Engineering, Lovely Professional University, Phagwara, Punjab 144411, India

²Department of Radiation Oncology, Mohan Dai Oswal Cancer Hospital and Research Foundation, Ludhiana Punjab 141009 India

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Abstract. The Precision of radiotherapy is checked based on the matching of pre-treatment 2D portal imaging/ CBCT to the reference image. The objective of this study is to find inter-fractional systematic and random setup errors (mm) for head and Neck cancer patients and also find setup margin for Planning Target Volume (PTV) at Mohan Dai Oswal Cancer Hospital Ludhiana Punjab. Inter-fractional motion errors were quantified for 10 Head and neck cancer patients who underwent image guided helical intensity modulated radiation therapy with Radixact X9 machine. One hundred fan beam computed tomography scans of 2mm slice thickness, 3.5 MV average energy and flattening filter free beam has been used to collect the data for the calculation of systematic and random errors. After patient immobilization, patient accuracy is checked with registration of pre-treatment image with reference planning image with the help of Accuray Precision image guidance protocol. For every patient 10 fan beam computed tomography images has been taken. Translational errors have been calculated in X, Y and Z direction to find systematic error (Σ) and random error (σ). The final PTV margin is calculated by van Herk's equation ($2.5\Sigma + 0.7\sigma$). The results of this study shows that mean translational errors varies from -2.3 mm to 3.3 mm in lateral direction (X), -3.6 mm to 1.7 mm in longitudinal direction (Y), -2.7 mm to 1.5 mm in vertical direction (Z). The mean and standard deviation (SD) for systematic errors are 1.467, 0.8, 0.923 and random error 0.0595, 0.02266, 0.03824 in X, Y and Z direction has been calculated. The Total Margin for CTV to PTV which include setup margin (mm) in X, Y and Z direction are 3.7 mm, 2.02 mm and 2.33 mm. In addition to that, a PTV margin of 5.00 mm is the appropriate margin for Mohan Dai Oswal Cancer Hospital's patients. This work conclude that CTV to PTV margin of 5.00 mm is suitable for image guided helical intensity modulated radiation therapy for Head and neck patients to ensure the minimum 95% coverage of dose to target

Keywords: Cancer, IMRT, Systematic error, random error.



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Conferences

1.

 LOVELY PROFESSIONAL UNIVERSITY <i>Transforming Education Transforming India</i>	Certificate No. <u>225381</u>	
		
Certificate of Participation		
This is to certify that <u>Ms. Rama Devi</u>		
of <u>Mohan Dai Oswal Cancer Treatment & Research Foundation Ludhiana</u>		
has given poster presentation on <u>Retrospective study of random and systematic errors in Head and Neck cancer</u>		
<u>Patients with Image guided Helical Intensity Modulated Radiation Therapy</u>		
in the International Conference on "Recent Advances in Fundamental and Applied Sciences" (RAFAS 2021) held on June 25-26, 2021, organized by School of Chemical Engineering and Physical Sciences, Lovely Faculty of Technology and Sciences, Lovely Professional University, Punjab.		
Date of Issue : 15-07-2021 Place of Issue: Phagwara (India)		
 Prepared by (Administrative Officer-Records)	 Organizing Secretary (RAFAS 2021)	 Convener (RAFAS 2021)

2.



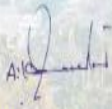
14th Annual Conference of Northern Chapter
Association of Medical Physicists of India
(AMPICON NC 2021)

Theme - "Emerging Challenges and New Frontiers in Medical Physics"

12th March 2022

Organized virtually by
Department of Radiological Physics Dr. Sampurnanand Medical College and Associated Hospitals,
Jodhpur

*This is to certify that **Mrs. RAMA DEVI**, Medical Physicist/ Radiation Safety Officer has participated in the 14th Annual conference of Northern Chapter Association of Medical Physicists of India.*

			
Dr. Ajai K Srivastav Chairman NC-AMPI	Dr. R K Bist Secretary NC-AMPI	Dr. Devesh Gupta Organizing Chairman AMPICON-NC-2021	Mr. Prabhat K Sharma Organizing Secretary AMPICON-NC-2021

3.



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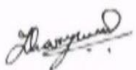
This is to certify that Prof./Dr./Mr./Ms. Rama Devi has successfully participated as Delegate & Presented Poster/ Oral Presentation on Comparative analysis of 2D, 3D. Gamma Index for Head; Neck cancer patient on Radixact X9 machine using PTW OCTAVIOUS 729 detector array in the 3rd International Conference of Pharmacy (ICP-2022) on the Theme of "Practice, Promotion & Publication of Innovation : A Way of Transforming Health" held on 09th & 10th November 2022 organized by School of Pharmaceutical Sciences in a collaboration with Indian Pharmaceutical Association (IPA) at Lovely Professional University, Punjab.



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Sri Herbasia Biotech



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Certificate of Attendance

No. TIMEA-2478

This certifies that

Ms. Rama Bhawani, Medical Physicist

M D Oswal Cancer Hospital India

Attended the

Monaco 3DCRT/IMRT /VMAT Training 5.51.10

Date: 12th to 15th Sept 2022

Delivered by: Bikramjit Singh

Issued by: Elekta Medikal Sistemler Tic. A.Ş, Istanbul, Turkey



HAMZA TATLI
Education and Training Director, RTIMEA



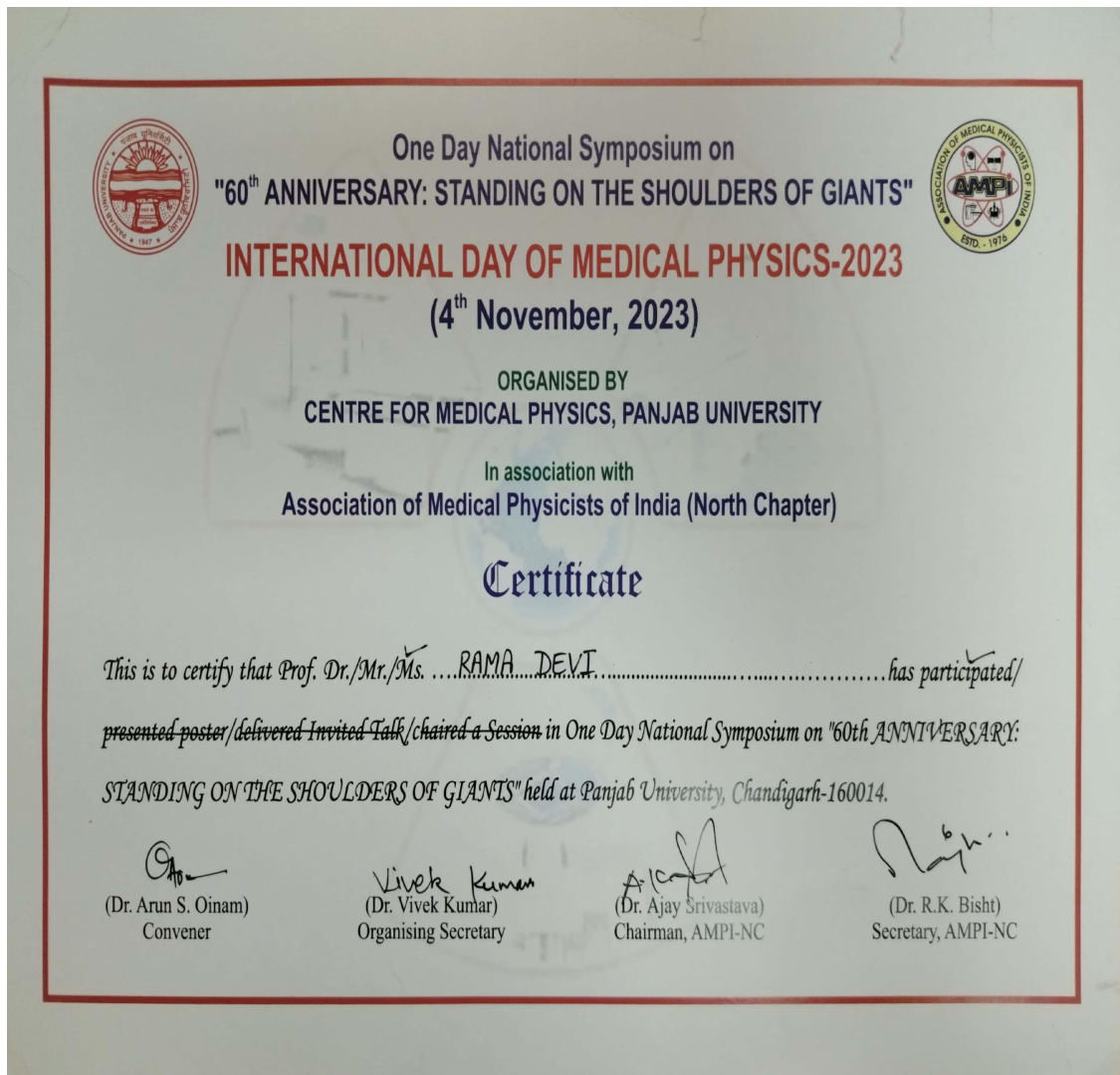
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6.



7.



8.



9.



10.



SCIENTIFIC APPROVAL



IEC-MOH
(CLA) ECR/365/Inst/PB/2013/RR-20
(DHR) EC/NEW/INST/2020/1103

Ref- IEC-MOH/2022/10

Date 31/03/2022

To,

Dr. Deepak Basandrai,

Dept. of Physics (Applied Sciences)

LPU, Jalandhar

Ref: Query related to project no. EC/01/2022 entitled, "Analysis of 6MV flattening filter photon beam in Craniospinal irradiation".

Dear Dr. Basandrai,

We have received from you the following document (s).

1. Application form for Initial review (Annexure01/SOP05/V2)
2. Study protocol (including protocol amendments)
3. Delegation of the responsibilities of study team
4. Budget Sheet
5. Detailed budget for proposed study
6. Conflict of Interest
7. Consent of Head of department
8. Current CVs of Principal investigator, Co-investigators
9. Application form for requesting waiver of consent (Annexure01/SOP19/V2)

At the Institutional Ethics Committee meeting held on 30-03-2022, the above mentioned documents were reviewed in full board along with a brief presentation by Ms. Rama Devi (Ph.D scholar)

The members who attended this meeting held on 30-03-2022 at which the above mentioned documents were discussed are listed below:

Name of Members	Role/Position on IEC	Designation/Affiliation	Gender
Dr. Dinesh Kumar Badyal	Basic Medical Scientist/ Acting chairperson	Member	M
Mr. Dinesh Gogna	Social Scientist	Member	M
Mr. Navdeep Sharma	Legal Expert	Member	M
Dr. Raman Arora	Clinician	Member	M
Mr. Komal Jain	Social Scientist	Member	M
Mr. Ravi Bhushan Vasishat	Legal Expert	Member	M
Mr. Satish Aggarwal	Lay Person	Member	M
Dr. Preeti Joseph John	Basic Medical Scientist	Member	F
Dr. Daljit Masih	Scientific Member	Member	M
Dr. Bimlesh Kumar Mohindra	Secretary	Member	M
Ms. Vasundhara Bhatia	Scientific Member/ Alternate Member Secretary	Member	F

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G.T. Road, Sherzaur By-Pass, Ludhiana-141 009 Ph. : 0161- 2676100, 101, 5224444, 5094539, FAX : 0161- 2672100, 2676102.
E-mail : contact@moh.org.in Website : www.moh.org.in

ETHICAL APPROVAL



**MOHAN DAI OSWAL
CANCER TREATMENT & RESEARCH FOUNDATION**

IEC-MOH
(CLA) ECR/365/Inst/PB/2013/RR-20
(DHR) EC/NEW/INST/2020/1103

Ref- IEC-MOH/2022/28

Date 30/06/2022

To,

Dr Deepak Basandrai,
Dept. of Physics (Applied Sciences)
LPU, Jalandhar..

Ref: The project no. EC/01/2022 entitled, "Analysis of 6MV flattening filter free photon beam in the craniospinal irradiation with different radiation modalities"

Dear Dr. Basandrai,

The meeting of the Institutional Ethics Committee (IEC) was held on 29/06/2022, Wednesday at 2:30pm, in the Board Room with Dr H.S. Kang as Chairperson. 11 members attended the meeting held on 29/06/2022.

The list of members who attended the meeting is as follows.

Name of Members	Role/Position on IEC	Designation/ Affiliation	Gender
Dr H.S. Kang	Chair Person	Clinician	M
Mr. Dinesh Gogna	Social Scientist	Member	M
Mr. Navdeep Sharma	Legal Expert	Member	M
Dr. Raman Arora	Clinician	Member	M
Mr. Komal Jain	Social Scientist	Member	M
Mr. Ravi Bhushan Vasishat	Legal Expert	Member	M
Mr. Satish Aggarwal	Lay Person	Member	M
Dr. Preeti Joseph John	Basic Medical Scientist	Member	F
Dr. Daljit Masih	Scientific Member	Member	M
Dr. Bimlesh Kumar Mohindra	Secretary	Member	M
Ms. Vasundhra Bhatia	Scientific Member/ Alternate Member Secretary	Member	F

The following member was absent:

Dr. Dinesh Kumar Badyal	Basic Medical Scientist	Member	M
Mr. Shiv Bhawan Mishra	Social Scientist	Member	M

It is to be noted that neither you nor any of your proposed study team members were present during the decision-making procedures of the Institutional Ethics Committee. In addition, the members of the IEC do not have any conflict of interest for the above mentioned study.

R7 Ground Floor, Main building | Mohandai Oswal Hospital

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