PEOPLE'S DEMOCRATIC REPUBLIC OF ALGERIA

MINISTRY OF HIGHER EDUCATION AND SCIENTIFIC RESEARCH

UNIVERSITY OF KASDI MERBAH OUARGLA

FACULTY OF MATHEMATICS AND MATERIAL SCIENCE

DEPARTMENT OF PHYSICS

Professional Master Thesis

Domain: Physics

Specialty: Medical Physics
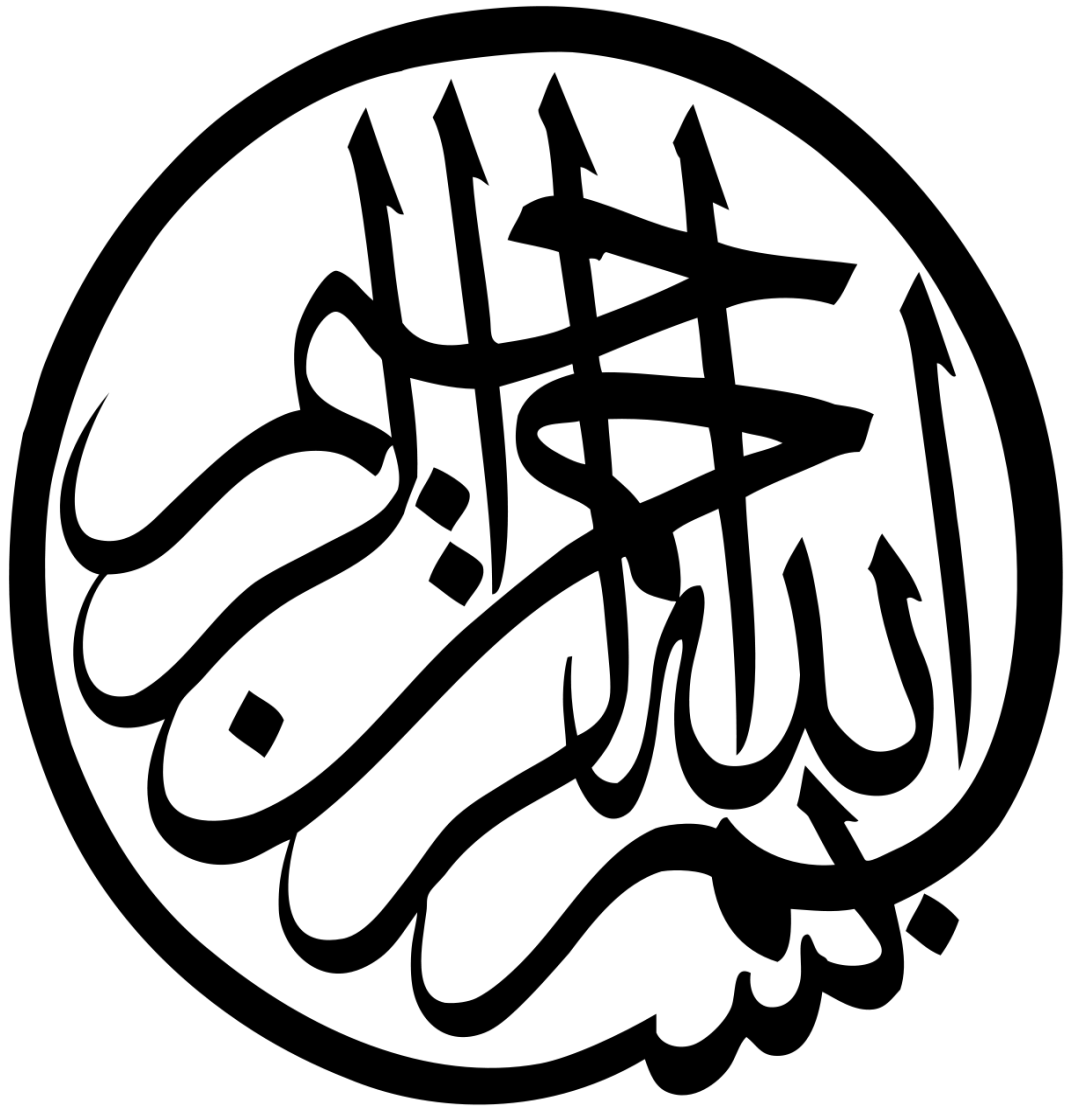
Presented by:

Benabdessadok Abdelhadi

Theme:

Stereotactic Radiotherapy

21/06/ 2023

In front of the jury members :

BOUANANE Rabah	University of Ouargla	President
BENMEBROUK Lazhar	University of Ouargla	Jury
NAOUN Lilia	CLCC-CHU Annaba	Supervisor
BENTOUILA Omar	University of Ouargla	Co-Supervisor

Academic year :2023/2022

<u>DEDICATIONS</u>

أهدي هذا العمل المتواضع :

‑ لوالدي الكريمين كرمز لكل الدعم والتشجيع و لأختي
العزيزة

‑ لكل أساتذتي و لأصدقائي ، لدعمهم في جميع الأوقات ،
و إيمانهم بي و أنا في بداية الطريق

‑ إلى كل المرضى و مرافقيهم نسأل الله لهم الشفاء

ACKNOWLEDGEMENT

القسم لما بعد التدرج و الدكتور تخة محمد و عميد الكلية بشكي جمال أشكرهم على جميع تسهيلات و دعمهم لنا

أتقدم بجزيل الشكر للفيزيائي الطبي على مستوى مركز مكافحة السرطان عنابة ، الاستاذ نصر الدين صناح صاحب الأسلوب الرائع و المتميز في إصال المعلومة

أتقدم بجزيل الشكر الى الانسة هاجر بودخان و الانسة هاجر بوقصة والسيد وسيم حفيان و السيد مولود مرحوم و السيدة بلحيط ج ، الفيزيائين الطبين على مستوى مركز مكافحة السرطان عنابة ، لم يبخلوا علينا بشيئ علما و خلقا

أتقدم بكل الشكر و الحب الى جميع الاطباء كلا بإسمه أذكر من بينهم د ليلى بوعكاز ، بروفسور منصوري سمية ، د عميرش ، د شران سليمة ، د بسكري ر ، د لعرافة ، د ياسي أمير ، د تراب ، د عويسية ، د عميرة ، علما و خلقا

أتقدم بجزيل الشكر لكل الممرضين و الإداريين و العمال على مستوى المركز كلا بإسمه أتمنى لهم التوفيق و السداد في حياتهم العملية و الخاصة

أتقدم بشكر و العرفان الى الاستاذ القدير الفيزيائي الطبي بالي محمد الصالح فيزيائي طبي في مصلحة العلاج الإشعاعي في عيادة أثينا قسنطينة ، كريما في علمه ، موفقا في معاملته الطيبة

أتقدم بجزيل الشكر الى مركز مكافحة السرطان و مصلحة الطب النووي ورقلة و مركز الابحاث النووية الجزائر و مركز مكافحة السرطان الوادي سوف على كل ما أجادوا به علينا من تكوين و تربصات في تخصص الفيزياء الطبية

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ABREVIATIONS

3DCRT	**3D Conformal Radiation Therapy**
AAA	**Anisotropic Analytic Algorithm**
AP	**Anterior-to-Posterior**
CBCT	**Cone Beam Computed Tomography**
CI	**Conformity Index**
CTV	**Clinical Target Volume**
DTA	**Distance To Agreement**
FFF	**Flattening Filter Free**
GTV	**Gross Tumor Volume**
IMRT	**Intensity Modulated Radiation Therapy**
ITV	**Internal Target Volume**
LR	**Left-to-Right**
MI	**Modulation Index**
MLC	**Multi-Leaf Collimator**
MU	**Monitor Unit**
OAR	**Organ At Risk**
PRO	**Progressive Resolution Optimizer**
PRV	**Planning Organ at Risk Volume**
PTV	**Planning Target Volume**
QA	**Quality Assurance**
SABR	**Stereotactic Ablative Radiotherapy**
SBRT	**Stereotactic Body Radiation Therapy**
SI	**Superior-to-Inferior**
SRS	**Stereotactic Radiosurgery**
SRT	**Stereotactic Radiation Therapy**
TPS	**Treatment Planning System**
VMAT	**Volumetric Modulated Arc Therapy**

1 <u>INTRODUCTION</u>

1.1 General Information on Cancer[1]

A cancer is the anarchic, uncontrollable and incessant division of a mutated cell. The cells first proliferate locally, without crossing the basal membrane: it is a in-situ carcinoma. Then they spread into the surrounding tissue and begin to dedifferentiate: it is an (invasive) cancer. When cancer cells are neovascularized and fully dedifferentiated, they have the ability to migrate through blood and lymphatic vessels, through which they will colonize distant tissues: this are (metastases).

1.2 Classification of Cancers

There is an international TNM classification for each cancer. It consists of: Classify at the time of its discovery, cancer according to three data.

- T: primary tumor: Classify the tumor according to the size and tissue location.
- N: regional adenopathy: Determines if the tumor is infiltrating to the lymph nodes and which area(s) lymph node(s) is or are affected.
- M: metastases: Indicates whether the carcinoma has migrated to other distant tissues.

Tableau 1: Stage of The Tumor

Stage 0	Tumor in situ (Tis2)	N0	M0
Stage 1	T1	N0	M0
Stage 2A	T0	N1	M0
	T1	N1	M0
Stage 2B	T0	N0	M0
	T1	N1	M0
	T3	N0	M0
Stage 3A	T0	N2	M0
	T1	N2	M0
	T2	N2	M0
	T3	N1, N2	M0
Stage 3B	T4	All N	M0
	All T	N3	M0
Stage 4	All T	All N	M1

Depending on the location of the lesion, the type of cancer and its stage, the invasion or not of the lymph node areas, the treatment (studied on a case-by-case basis) will be different in radiotherapy.

In light of the spread of cancer at terrible rates in recent years and worldwide, and with the different and diverse injuries, as well as the registration of new types of intractable conditions, and in light of the development of diagnostic and treatment methods and their compatibility according to the pathological condition, such as surgery, chemotherapy and radiotherapy Hormonal therapy, immunotherapy, and other treatments. In our work, we choose this radiation therapy as a method for treating cancer, and this is in accordance with the specialty of medical physics, which aims in its formation to apply the use of ionizing and non-ionizing radiation in the field of medicine.

In the course of radiobiology for radiotherapy into effects of ionizing radiation on DNA. The aim of radiotherapy treatments is to damage the tumor cell in order to prevent it from reoccurring. The study of the effects of radiation on cells is called radiobiology. Radiation biology attempts to determine the best treatment regimen for obtain the desired effects, i.e. the elimination of cells tumors and the protection of healthy cells surrounding the tumor.

The characteristics of a treatment regimen are

    a. Type of radiation

- ✓ Photon (60kV to 25 MV), electron (4-22 MeV)
- ✓ Neutron, proton, β+, β-...

    b. The total prescribed dose

- ✓ Type of tumor
- ✓ Tissue tolerance
- ✓ Size of the volume processed
- ✓ Type of radiation

Photons are classified as indirectly ionizing radiation. During their interactions with the tissue, high energy electrons are produced and will cause the damage biological.

Electrons are classified as directly ionizing radiation. The high electrons energies damage the DNA (deoxyribonucleic acid) of the cell. They damage it 24 Chapter I Theory of ionizing radiation directly (30%) or indirectly (70%) by interacting with water and creating radicals free which will damage the DNA.

Photons can be X-rays produced by devices such as orthovoltage (60-300 kV), linear accelerators (4-25 MV). Photons can also come from decay radioactive isotope (γ rays) such as Cobalt 60, Cesium 137, Iridium 192, Palladium 103, Iodine 125, …

Electrons can be produced by linear accelerators (4-22 MeV). They can also come from the decay of radioactive isotopes (β rays) such as iodine 132

Within the framework of our work, we will be interested only in the beams of photons and electrons of high energies used in external radiotherapy.

1.3   Definition of radiotherapy

Radiation therapy is a method of treatment in which ionizing radiation is used, as it aims to give the appropriate radiation dose to the tumor and to preserve the neighboring cells and organs by adjusting the lowest dose allowed to be given according to agreed medical studies.

Radiotherapy is the use of ionizing radiation in the treatment of certain diseases, above all, cancers. It is often associated with surgery and/or chemotherapy during treatment for locoregional cancers. It uses ionizing radiation to destroy cells cancer cells by blocking their proliferation. It acts on the tumor itself and also on the satellite nodes.

Radiotherapy is regulated by a set of techniques developed with the development of technology and information, after radiotherapy used to result in exposing healthy organs nearby to radiation in large doses that negatively affected the quality life of the patient. Today, these techniques have become a solution to this problem, and we mention among them 3DRT, IMRT, VMAT, SRT Where each technology has protocols and features that set the limits of its use.

A permanent evolution of this processing mechanism is present. Since the dose reduction, the side effects are much less important but still remain even present. The amount of radiation absorbed by the patient is calculated by radio physicists 6 , this step is called dosimetry.

1.4   Historical Radiotherapy

was born with the discovery of X-rays by W.K. Röntgen in 1895 and that of radium by Marie Curie in 1898. From 1903, she described the beneficial actions rays of radium on the cancerous cells which marks the birth of the brachytherapy.

As early as 1896, doctors who had access to these discoveries very quickly observed that X and gamma radiation produce effects on living tissue: they have the property of shrink cancerous tumors and, in some cases, sterilize them. It's the start of radiotherapy.

However, it is limited in its applications by the difficulty of being able to irradiate the tumor evenly and at a sufficient dose, without excessively irradiating the healthy tissues around it. In 1930, the team from the Institut Curie carried out work on the dose splitting in order to limit side effects, and in 1936, François Baclesse (Institut Curie) lays the foundations for conservative treatment of breast cancer.

It was not until the 1950s that radiotherapists had methods selective and precise irradiation thanks to the introduction of high-energy radiation.

The latter are those whose energy exceeds 1 MeV. They are emitted by devices ("bombs") of cobalt-60 or linear accelerators, the first of which was built in 1952. From this period, advances in radiotherapy were steady until day.

They are largely due to the simultaneous development of physical dosimetry (the dates back to 1960), imaging, accelerator technology and the introduction quality checks.

A better understanding of the natural history of cancers and their mode of evolution, combined with the evolution of surgery and chemotherapy, have also contributed significantly to improving the efficiency of the radiotherapy, while assuring patients the minimum of side effects.

In 1990, three-dimensional conformal radiotherapy was born: the first scanner and computer applications for dosimetry are implemented.

Through our work, we chose a technique SRT as a technique specialized in treating tumors of small size, less than $5cm^3$, by giving a large radiation dose and treatment fractions that are less than in other technique , and we can using as an alternative to chemotherapy .

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2   DOSIMETRY[2]

2.1   Physical characteristics of a photon beam

2.1.1   Energy parameters

- Energy flux: total energy transported by the beam per unit time.
- Energy intensity in a given direction

2.1.2   Spatial distribution

It is provided by the energy intensity indicator which is the curve I = f (direction) that we saw for the RXs. It will be recalled that, in the case of an isotropic emission, we have

$\quad$ I = Φ/4π ….. (I -1)

2.2   Characteristics in the material

In this case, an element of matter, located around a point P will receive photons direct and scattered photons. In the sphere element of radius dr, the section surface which is perpendicular to the scattered radiation is always π.(dr)², regardless of the direction of the scattered radiation. He It is therefore appropriate to adapt the definitions which involve a fixed surface dS, so we will have:

- irradiance $E = \frac{dF}{\pi.(dr)^2}$ ……(I -2)

- and the energy fluence $F = \frac{dW}{\pi.(dr)^2}$ …… (I -3)

2.3   Transfer of energy between a beam of photons and matter

2.3.1   KERMA

The term KERMA is the English acronym for (Kinetic Energy Released per MAss unit). it is the quotient of the sum of the initial kinetic energies dEtr of all the charged particles set in motion by the uncharged particles in an element of matter of mass dm:

$$K = \frac{dW_d}{dm} \quad …… \; (I -4)$$

The kerma unit is the joule per kilogram (J.kg-1), expressed in Gray (Gy). Kerma is only defined for neutral particles, photons and neutrons. the absorbed dose can be assimilated to the kerma under certain conditions, detailed later.

2.3.2 Absorbed dose D (Gy)

Is a macroscopic quantity recommended by the International Commission on Radiation Protection (ICRP 26,1977; ICRP60,1991; ICRP 74). this quantity is defined as being the ratio of the average energy communicated by the ionizing radiation to the matter in a volume V, to the mass M of the matter contained in this volume element.

$$D = \frac{dw_a}{dm} \quad .....(\text{ I -10})$$

In a certain number of cases, the dose may be considered equivalent to the most sensitive tissue.

2.3.3 Bragg Gray's principle

During irradiation of a medium of mass m with a beam of charged particles having an average energy W needed to create an ion pair, a current J will be created, and The absorbed dose in this medium will then be defined as follows:

$$D = \frac{J.W}{m} \quad .... (\text{ I -5})$$

Then the absorbed dose in the medium m1 is related to the dose absorbed in the cavity by the Next relationship:

$$D = J_G . S_{P,a} . W \quad ....(\text{ I -6})$$

J_G : is the number of ion pairs formed per unit of mass of the cavity gas.

W: is the average energy needed to create a pairions.

D: is the absorbed dose.

$S_{P,a}$: is the ratio of mass stopping powers for secondary electrons in the medium, and in the gas constituting the cavity.

The devices for this type of measurement are called" ionization chambers."

— The dose in a small air cavity in water is related to the dose in water by:

$$D_{eau} = D_{air} \frac{\left(L_\Delta / \rho \right)_{eau}}{\left(L_\Delta / \rho \right)_{air}} \quad ......(\text{ I -7})$$

Bragg Gray and Spencer-Attix theory

— for a beam of photons, to pass from one medium to another:

$$D_{milieu} = D_{eau} \frac{\left(\mu_{ab} / \rho \right)_{milieu}}{\left(\mu_{ab} / \rho \right)_{eau}} \quad ....(\text{ I -8})$$

− for an electron beam, to pass from one medium to another:

$$D_{milieu} = D_{eau} \frac{\left(s/\rho\right)_{milieu}}{\left(s/\rho\right)_{eau}} \dots\dots (\text{I -9})$$

2.4 Spatial dose distribution in external beam radiotherapy

The goal of external beam radiation therapy is to use ionizing radiation to treat lesion (tumor) without necessarily resorting to surgery. Parameters to Calculating the energy absorbed has just been seen but, in reality, the beam changes at the course of his progression in the subject; It is therefore necessary to determine the dose deposited in surface area compared to that deposited at depth as a function of the volume useful for irradiation.

a) Fluence of particles: The particulate fluence q is the ratio of the number of particles dN incident on a sphere of section of unit section da, it is expressed in particles per m2

b) Energy fluency : The energy fluence u , is the ratio of the incident radiant energy dR crossing a sphere of unit section da, it is expressed in J.m-2

2.4.1 Percentage Depth Dose (PDD)

This is the ratio of the dose at a point at a depth x to that taken as a reference at a point A. This reference point will be taken where the absorbed dose is maximum on the journey: in surface by radiations < 1 MeV, in depth for high energies. This yield may vary due to geometric factors:

− if the beam is divergent, the irradiation varies as 1/d2 , it will be interesting in the case of superficial tumors by placing the source near skin

− if the beam is parallel, by collimation, we can irradiate deep tumors by placing the source at a great distance from the skin.

From what we know from the interactions, the performance in depth goes above all vary with the nature of the radiation.
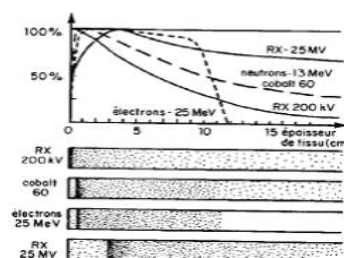
Figure 1: Transmission curves of the back in depth and corresponding ionizations

We observe that:

- The low energy X are very attenuated from the first centimeters
- When the energy of the electromagnetic wave X or γ increases, the tissues superficial are less and less exposed to maximum energy and a dose can be delivered at significant depths
- The e- deposits their energy close to the skin, with a yield that is noticeably constant until the energy is exhausted.

2.4.2   Isodoses Curves

Isodoses An isodose curve is, in a plane passing through the axis of the beam, the locus of the points receiving the same radiation dose under fixed conditions irradiation (imager I.5).
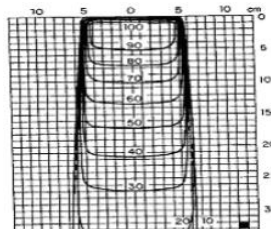
Figure 2: Isodose curves (profiles) of an energy photon beam

Isodoses are moving further and further away from theoretical trajectory when one progresses in the depth of the tissue but deviate from it less and less as the energy increases.

What has just been said in a plane is valid in all the planes which revolve around the axis of symmetry. So, the set of isodose curves will envelop an isodose surface which will be the locus of all points that have the same depth yield. The volume at irradiate will therefore be included in the isodose curves which will determine the calculation of the doses deliver to tissues.
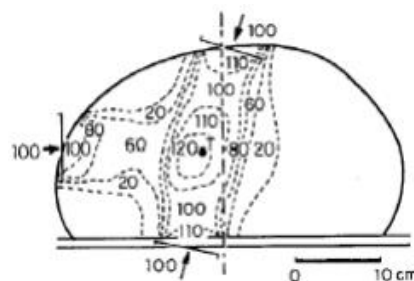
Figure 3: Dose distribution in a treatment with different irradiations

We must therefore find a treatment strategy that allows the dose to be increased in the tumor. without increasing the dose in healthy tissues: the technique consists of using several trajectories.

In this way, the healthy tissues crossed are never the same and the doses partial to the tumor accumulate.

3   <u>RADIATION THERAPY SYSTEM DELIVERY[3]</u>

3.1   Introduction

External beam radiation therapy for cancer uses radiation of different qualities. the radiation most commonly used today are photons and electrons. The choice of the type of radiation and the energy of the beam depends on the nature of the tumor, its anatomical location, its size, its extension and its stage. electron beams are employed in particular when the target volume covers a very radiosensitive healthy organ, such as the lungs and the spinal cord. The limited path of the electrons of given energy makes it possible to minimize the dose in the neighboring tissues. To treat deeper tumors, photon beams are used, which are more penetrating than electron beams.

3.2   Treatment devices used in external radiotherapy

Applied physics studies have relied on the production of photon beams by various: X-ray tube, cobalt-60 unit, or linear accelerators (LINAC). In addition, the latter produces electronic packages. Thanks to this new equipment, it is now possible to properly irradiate all types of tumors, even the deepest ones. The benefit soon became apparent and the clinical results completely changed.

3.2.1   X-ray tube

In the course of X-ray and source the ray, the tubes x-ray are among the first treatment devices used in radiotherapy. Although these devices are best known for their diagnostic role, they have been used since the turn of the century to treat various types of cancer. The structure and working principle of therapeutic and diagnostic X-ray tubes are practically the same. the electrons emitted by thermoelectronic effect are accelerated by an electromagnetic field applied between the electron gun and a sheet of tungsten. the X-ray beam is produced by the braking of electrons in the tungsten target.

X-ray tube voltage and focus size are the main differences between diagnostic and therapeutic use of this device.

In radiotherapy, the accelerating voltages used in X-ray tubes can be up to 300 kV, while in diagnostics they are between (50-150) kV. Therapeutic X-rays are usually filtered using thin copper or aluminum plates to remove the low energy photons they contain. This technical difficulty in creating high accelerating voltages has limited the use of the X-ray tube in radiotherapy for the treatment of skin cancers The attenuation of these beams of photons

according to the depth being fast, they cannot therefore be used to treat tumors located more than 2cm under the skin without depositing an excessive dose on the surface
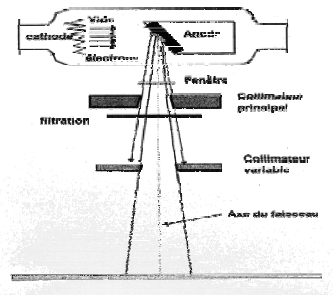
Figure 4: X -ray Tube

3.2.2 Cobalt-60 Unit

In the course of source the ray unit cobalt-60 it using several radiotherapy centers still have a source of cobalt-60 which is a continuous source of radiation. the source is in the form of radioactive grains and/or discs arranged inside a double stainless-steel capsule, the actual dimensions of the source of which are those of the volume occupied by the radioactive material alone and most often correspond to a 2cm diameter

Cobalt-60 decays by emitting β radiation and 2 γ photons, with respective energies of 1.33 and 1.17 MeV. The β radiation is stopped by the capsule containing the radioactive body, and only the γ photons are usable for the treatment of patients. the decay period of Cobalt-60, equal to 5.27 years, corresponds to a decrease in activity of the order of 1.51% on month.
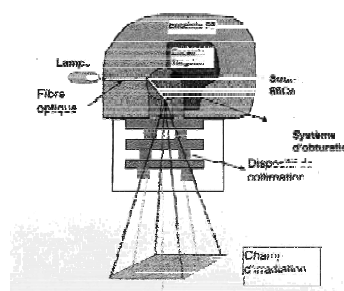
Figure 5: Cobalt-60 Unit

The source is surrounded by a protective enclosure in heavy metal in which is fitted a conical opening allowing the passage of radiation. It is usually made of lead and tungsten. its thickness must be calculated to stop the radiation that is emitted in all directions. a collimation system consisting of irradiation beams of variable dimensions. all this together constitutes the

irradiation head, which is attached to the end of an arm which rotates from a horizontal axis or which moves vertically

3.2.3 Linear accelerator

The linear accelerator uses very high frequency (MHz) electromagnetic waves to accelerate charged particles, electrons, to high energies through a linear tube.
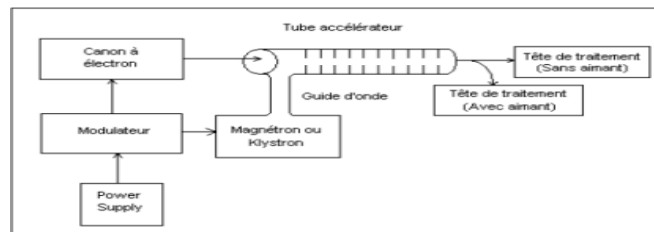
Figure 6: Block diagram of a linear accelerator

The power supply unit provides voltage to the modulator whose role is the production of electromagnetic waves which are then sent into the waveguide. the modulator intervenes again for the synchronization between the electromagnetic wave and the electrons which are sent by the electron gun. They must arrive in phase with the electromagnetic wave to overlap it all along the acceleration tube. the latter is made up of several cavities allowing the electrons and the electromagnetic wave to be in phase. It is in this tube that the electrons will seek their speed (energy). Moreover, it is also what determines the energy of the radiation beam. the radiation beam can be composed directly of these accelerated electrons or of high energy photons. to create the beam of photons, it suffices that the beam of electrons accelerated by the electromagnetic wave strikes a target of tungsten for example (khan, 1994). photons are created by two types of mechanisms, bremsstrahling and characteristic X-rays. the probability of producing bremsstrahlung is proportional to the square of the atomic number of the material constituting the target.

4   THE CHAIN OF TREATMENT IN EXTERNAL RADIOTHERAPY

The objective of radiotherapy is to deliver a sufficient dose and as homogeneous as possible to the tumor while preserving the surrounding healthy tissue as well as possible and in particular the organs at risk, organ for which one cannot exceed certain doses without risking complications. a series of procedures that make it possible to know and optimize the dose distribution in the different tissues and the tumor to be treated must be performed. all of these procedures are called a processing chain

4.1   Acquisition of patient data

The acquisition of patient data is the essential first step in radiotherapy, the identification of the target is an essential step since it directly conditions the success or failure of the treatment. In radiotherapy, priority is given today to imaging (multi-modality), that is to say the joint use of several types of examinations to identify the volume to be irradiated. the therapeutic dose to be delivered and the critical doses of the organs at risk can be fixed at this stage on the basis of the biological effects of the radiation. it allows to choose the irradiation technique, but these imaging data do not allow to determine the ballistics of the treatment for treatment planning

4.2   Simulation

Before beginning radiotherapy treatments, a patient must first complete several preliminary steps. The treatment prescribed by the radiotherapist is first simulated using a device called a simulator. This device is in fact a X-ray tube mounted on a structure which has the same movements and the same geometric displacements as a medical accelerator the simulator first allows to define the dimensions and the exact position of the target volume by taking x-rays of the anatomical site to be treated. the position of the patient as well as the configuration of the treatment table and of the accelerator making it possible to irradiate the target volume as efficiently as possible are determined at this moment. some simulators can produce digital axial tomographic slices (simulator-CT).

Currently, the ballistics of the treatment is determined more and more, during the stage (planimetric study) by what is commonly called (virtual simulation) the simulator can make it possible to anticipate or verify the planned ballistics. virtual simulation is increasingly used to define treatment ballistics. It requires the acquisition of the patient's anatomical data thanks to a large number of CT sections (CT scanner-simulator dedicated to the radiotherapy department

or access to a diagnostic scanner), a three-dimensional reconstruction of the various organs and the tumor is thus feasible.

4.3   The contouring anatomy

The contouring anatomy   GTV palpable tumor volume and the organs at risk OAR represents one of the important tasks of the radiation oncologist on the planimetry consoles (virtual simulation console). once the target volume and the positioning of the patient have been determined, provisional dose calculations are carried out using specialized software, the treatment planning system. this computer system makes it possible to calculate the dose distribution inside and around the target volume, to visualize the anatomy of the treated volume as well as the irradiation ballistics.

Treatment planning is the set of operations that make it possible to calculate the dose distributions as well as the irradiation time necessary to distribute the prescribed dose to the target volume. its role is also to establish the isodose curves which represent the distribution of the dose in the irradiated volume (tumor and healthy tissues)

4.4   Treatment Planning System (TPS)

The treatment planning system must indeed have the absolute dose rates in the water for the available beams, their transverse profiles in this same medium as well as the attenuation of the radiations as a function of the depth in the water. this system can also take into account the internal heterogeneities of the human body. the dose distribution obtained can be modified by adding a block of lead to the beam to protect radiosensitive organs. the dosimetry must be approved by the radiation therapist.

Treatment planning requires knowledge of:

- The patient shape (external contours)
- The position of the beams in relation to these contours
- Position and shape of target volumes and critical organs (internal contours)
- The density of the heterogeneities of certain internal contours

The external contours can be obtained from a shaper or scan sections made in the treatment position.

They are then deduced manually or automatically from these images (segmentation).

Internal contours are then defined using imagery dosimetry is the means of obtaining the dose distributions within the target volumes, of the critical organs and at all the levels that will be deemed necessary in order to be able to assess the quality of the treatment ballistics.

4.5   Implementation

With each treatment, the patient is installed on the treatment table in a precise position. The marks on the patient's skin made during treatment simulation are aligned with laser light centerers. These beams, spread with cylindrical lenses on perpendicular planes, intersect precisely at the isocenter of the treatment apparatus. The reproducibility of the patient's positioning to within a few millimeters is essential in order to provide an effective and safe treatment. The patient must obviously remain perfectly still during irradiation

5   RADIOTHERAPY TECHNIQUES

In the course of techniques modern on radiotherapy

5.1   3D Conformal Radiation Therapy (3CRT)

3D CRT is a cancer treatment that allows doctors to direct radiation beams to conform to tumor shapes.

In the past, beams only matched the height and width of the tumor and exposed healthy tissue to radiation.

Advances in imaging technology now let doctors find and treat the tumor in a more precise way.

CRT uses targeting data to focus right on the tumor and avoid the healthy tissue around it. This exact targeting allows for higher levels of radiation in treatment, which is better for shrinking and killing tumors.

5.2   Conformational Intensity Modulated Radiotherapy (IMRT)

The principle of conformal radiotherapy is improved by modulating, during each session, the dose rate delivered by each beam. This modulation is ensured thanks to a mutilated collimator, the blades of which are set in motion during the treatment session.

Breath-dependent radiation therapy When treatment sessions last several minutes, the patient's organs can move slightly mainly because of breathing, this is the case with tumors that are located in a mobile organ such as the lungs. In order to improve the accuracy of treatments, techniques for controlling the beam of radiation to the movement's organs are being developed and are beginning to be used in some services

5.3   Volumetric Modulated Arc Therapy (VMAT)

Volumetric modulated arc therapy (VMAT) is a novel radiation therapy technique that delivers the radiation dose continuously as the treatment machine rotates. This technique accurately shapes the radiation dose to the tumor while minimizing the dose to the organs surrounding the tumor.

5.4   Stereotactic radiotherapy

Recently, high-precision radiotherapy techniques have been developed using fine beams of photons or electrons which converge at the center of the lesion. The principle of this treatment, which is also called radiosurgery, is to deliver a high dose of radiation into abnormal intracranial structure by decreasing tissue radiation breasts around the lesion. This treatment is well suited for small lesions and certain cerebral vascular malformations. Important developments in the use of this technique and radio surgery in several sessions to reduce the toxicity of the treatment of larger lesions: this is steroid radiotherapy split.

6   STEREOTACTIC RADIOTHERAPY TECHNIQUES[4]

Stereotactic radiation therapy (SRT) is an external beam radiation therapy procedure that uses a combination of stereotactic apparatus and multiple coplanar and noncoplanar beams to focus radiation to a small but well-defined tumor.

- If SRT is applied to a tumor in the brain (intracranial) using a single fraction (most typically) or a few ones (no more than five, typically), it is called stereotactic radiosurgery (SRS).
- Stereotactic Radiosurgery (SRS): Treatment is complete in a single fraction in the skull
- 12-70 Gy in 1 fraction
- Prescribed to 50- 80% isodose line; 20-50% Hot areas in center
- Tumors and functional medical conditions

If SRT is applied to tumors outside the brain (extracranial), it is called stereotactic body radiation therapy (SBRT).

Stereotactic Radiotherapy (SRT) : Treatment is complete in multiple fractions (usually 2 – 5) in the skull

- 12-70 Gy in 2-5 fractions
- Prescribed to 50- 80% isodose line; 20-50% Hot areas in center
- Tumors and functional medical conditions

Stereotactic Body Radiotherapy (SBRT) or (SABR) : Treatment can be single fraction or multiple fractions, but is outside the brain. Examples: lung, liver, spine, prostate, etc.

- 16–54 Gy in 1-5 fractions (Europe and other countries may use up to 70Gy in 10fx)
- Prescribed to 70-80% isodose line ; 20-30% Hot Areas in center
- Tumors

6.1   Major Characteristics of SBRT/SRS

- Stereotactic Body Radiation Therapy (SBRT) refers to a stereotactic radiotherapy procedure for treating extracranial tumors with ultrahigh doses per fraction (6 to 30Gy), in a hypo-fractionated regimen of five or fewer fractions
- Stereotactic Radiosurgery (SRS) – Single fraction stereotactically targeted radiation therapy
- The goal of SRS/SBRT treatment is to "ablate" tissues within the PTV

- Dose inhomogeneity inside the PYT was considered acceptable (potentially advantageous) and not considered a priority in a plan design
- Maximum point dose up to 160% of Prescription Dose is common for SRS/SBRT plans
- The main objective of the plan is to minimize the volume of those normal tissues outside PTV receiving high dose per fraction
- SBRT has been mostly applied to the tumors in the Spine, Lung, Liver, Pancreas, Kidney and Prostate
- SRS is used for metastatic Brain and Paraspinal tumors
- Conformation of high dose to the target volume together with a rapid fall-off of dose outside the target is of critical importance in minimizing damage to normal tissue
- SBRT practice requires high level of confidence in accuracy of the entire treatment delivery process, which is accomplished by the integration of:
  o Modern imaging
  o Simulation
  o Treatment Planning
  o Delivery technologies
- Large dose per fraction delivered in fewer fractions (single fraction for SRS)
- Applicability only to well-circumscribed tumors → max cross-sectional diameters ≤ 5 cm (we also use 600cGy x 5 fxs for larger tumors)
- Small or no margins
- Need for patient immobilization and respiratory motion management
- Higher frequency of patient monitoring and geometric verification through image guidance
- SBRT/SRS training for all staff (Physicians, Nurses, Radiation Therapists, Physics)

6.2   Stereotactic Equipment

In SRS, the accuracy of beam delivery is strictly controlled by a specially designed stereotactic apparatus (e.g., rigid head frame, soft head frame) that immobilizes the patient during treatment and is used through all steps of the process: imaging/simulation, target localization, head immobilization, and treatment setup including image-guided radiation therapy (IGRT) (e.g., ExacTrac).

In SBRT, the accuracy is aided by appropriate patient immobilization (e.g., abdominal compression, body-fix, gating) and IGRT procedures during treatment (e.g., Cone Beam CT).

6.2.1   Gamma Knife[5]

   This machine utilizes a helmet containing 201 separate 60Co sources arranged in a 1608 sectored array. These are focused onto a target with the aid of tungsten secondary collimating shells that define treatment spheres of 4 mm, 8 mm, 14 mm, or 18 mm in diameter. This unit represents the gold standard of geometrical precision, giving a dose delivery to within G 0.4 mm (2 SD). It is robust and simple to operate, with mechanical movement restricted to a couch top that longitudinally docks into the treatment head (Imger П-1) . Translational adjustments to the patient's head frame align the planned isocentre with the focus of the cobalt-beam pencils. Its disadvantages lie in its high capital cost, its lack of versatility as a radiotherapy tool and its 201 radioactive sources which need replacing after 5–10 years of use.[6]

Figure 7: Gamma-knife

   The ^{60}Co Gamma knife radiosurgery unit. A tungsten secondary shell is shown positioned over the patient's head prior to treatment, enabled by dacking the couch inside the safe , which contains the primary collimator and ^{60}Co Gamma ray sources

6.2.2   Cyber knife [7]

   The cyberknife system is the first and only fully robotic radiotherapy device cyberknife uses an approach called stereotactic (SRS/SBRT) , delivering precise doses of radiation with extreme accuracy and accounting for tumor or patient movement in real time . (cyberknife.com)

  − Set of circular cones or iris aperture

  − Robotic Gantry

  − Typically, ~200 beam angles

  − 2D kV for setup and intra-fraction motion monitoring
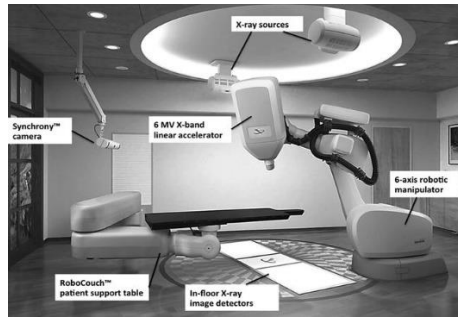
Figure 8: Cyberknife

Collimators for CyberKnife

- 12 fixed collimators – 5 mm to 60 mm in diameter
- Iris variable collimator – tungsten blades shape apertures 5 mm to 60 mm in diameter
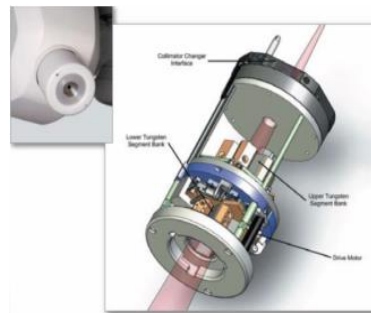
Figure 9: Collimators for Cyberknife

6.2.3 Linear Accelerator[8]

The early linac-based systems used neuro-surgical floor stands (Imager Π-4), which provided accurately engineered, precise vernier movement of the patient's head support. This enabled precision movement of the patient so the centre of the patient's lesion could be accurately positioned at the treatment isocentre. During the last 10–15 years, linac manufacturers have introduced specialised, mechanically improved treatment gantries, patient support couches and beam-shaping devices capable of more precise treatment delivery. These specialised units (Friedman and Bova 1989; Yin et al. 2002) have almost comparable accuracy to the Gamma Knife, but offer greater flexibility for a broader range of treatment options. However, such linac-based facilities require carefully designed quality assurance programs to maintain the high precision needed. This, along with the linac's greater operational complexity, servicing needs and potential for breakdowns, all demand greater staffing resources. The standard stereotactic beam delivery accessories for a linear accelerator are a set of quickly interchangeable, circular holed, tertiary collimators, which define circular crosssection beam pencils ranging typically from 10 mm to 50 mm in diameter in 2.5 mm steps. These can be augmented by the secondary

collimators for more flexible conformation if the corresponding treatment planning software is available (Hacker et al. 1997). For fixed field, conformal SRT, the minimum requirement is a specialised blocking system (Figure 45.3), as this can be made more precise and less prone to collision problems compared to conventional blocking trays. Micro-multileaf collimators (Shiu et al. 1997; Cosgrove et al. 1999), although expensive, are very efficient and technically sophisticated for stereotactically guided treatments. Other hardware requirements include such items as stereotactic frame mounting brackets, fiducial systems, setup boxes, a locking system for the couch top, stable precise room lasers, and a set of customised quality assurance tools for alignment and dosimetry checks (Warrington et al. 1994).
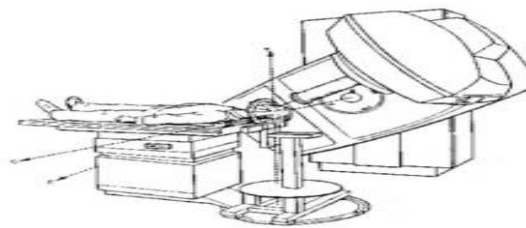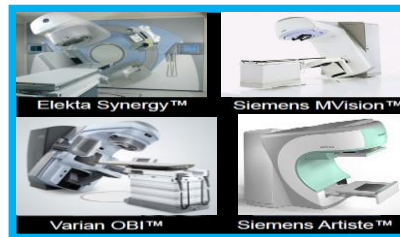
Figure 10: Linear Accelerator

Tableau 2: Linac-Based SBRT/SRS (MLC) and (HiDef MLC)

Table (П.1):	
Linac-Based SBRT/SRS (MLC)	**Linac-Based SBRT/SRS (HiDef MLC)**
Small MLC leaves	**Small MLC leaves: 2.5 mm**
Only need 1 Isocenter per lesion	**Only need 1 Isocenter per lesion**
More flexibility in technique:	**More flexibility in technique:**
Static beam	**Static beam**
Dynamic Conformal Arc	**Dynamic Conformal Arc**
IMRT	**IMRT**
VMAT	**VMAT**

6.3   Stereotactic Treatments[9]

There are numerous benefits…

6.3.1   For Clinics, Costs, and Society

    a.   Treat more patients, reduce wait times, reduce cost per patient

    b.   Improve access to care

    c.   Enable a healthier, loving society

6.3.2   Access to more treatment options

    a.   Frail patients who can't get surgery

    b.   Oligometastatic disease

    c.   Reirradiation

    d.   Less treatment time and costs

    e.   Equal or better outcomes

7   PHYSICS OF SMALL FIELDS [10]

7.1   Definition

We using in stereotaxic technique Small Fields

1) At least one of these conditions is fulfilled:

   a) there is a loss of Lateral Charged-Particle Equilibrium (LCPE) on the beam axis

   b) there is partial occlusion of the primary photon source by the collimating devices on the beam axis

   c) the size of the detector is similar or large compared to the beam dimensions

2) Loss of LCPE and density effect : depending on the detector size, the volume effect will reduce the signal in the ce , If we normarlize uncorrected profiles to the CAX, we will artificially broaden the penumbra, overestimate the field width and also the dose out-of-field.

3) Loss of LCPE :

   ✓ beam-related condition

   ✓ Occurs if the beam half width is smaller than the maximum range of secondary electrons that contribute measurably to the absorbed dose
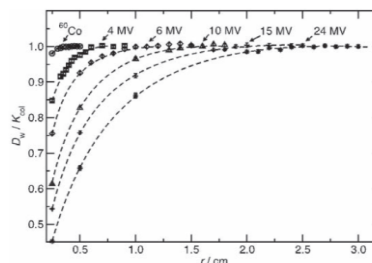
Figure 11: Loss of LCPE

rLCPE (cm) = $a * Q - b$ ....(П.1)

where

- Q is TPR20,10 or %dd(10)

- a, b are fit coeffs to MC data

 The loss of lateral charged particle equilibrium is a beam related condition.

 Charged particle equilibrium is a Fundamental principle of dosimetry and occurs when

Dose = Kcol

In the graph we can see in which distance, from the edge of the field in, Where the equilibrium occurs depending on the beam energy.

For a 6MV beam, this distance is about 1,1cm

I it possible to correlate range of the lateral equilibrium if you know the quality index of the beam (TPR20,10 or PDD10).

Obtained by Monte Carlo calculations

7.2 Practical condition:

For a given beam quality Q, the distance L from the detector outer boundary to the field edge is smaller than rLCPE(Q)
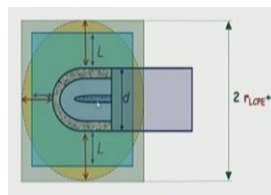
Figure 12: The detector

In other words:

To achieve CPE (not small fields): FWHM > 2 * rLCPE(Q)

In practice, a small field is a field that the distance from its edge to the outer part of the detector is smaller than the range for lateral equilibrium

In other words: To achieve CPE (not small fields): Full Width at Half Maximum is greater thatn rLCPE(Q)

It is important to note that the full width at half maximum is used in the definition of the condition here, not the nominal field size. We will see later why.

Preliminary conclusion here is that small field definition depends on beam quality and detector size

7.2.1 Partial occlusion of the photon source
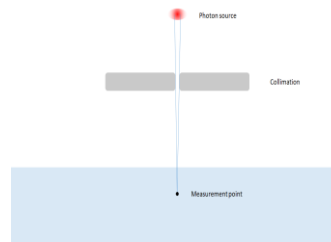
Figure 13: Beam Related Condition

The primary photons coming from the periphery of the source are blocked by the collimation – less photons = lower output.

This is a very important thing: in very small field sizes, the output fator drops quickly not Only because of less phantom and collimator scattering but also because of the reduced photon fluence from the source

The central axis will receive mainly photons coming from the central part of the source, which are more energetic = different spectrum (harder). The response of the detector may be affected due to spectrum changes.

It is important to note that this primary source occlusion effect becomes relevant when the field size is comparable to or smaller than the size of the primary photon source

This primary source occlusion effect becomes important when the field size is comparable to or smaller than the size of the primary photon source

For modern linear accelerators where the primary photon source size is not larger than 5 mm, direct source occlusion usually occurs at field sizes smaller than those where lateral electron disequilibrium starts

7.2.2 Focal spot size in real life

Old Siemens and Varian linacs have focal spots around 2-4mm. For modern linear accelerators like True Beam, have focal spots no bigger than 1mm.

Direct source occlusion usually occurs at field sizes smaller than those where lateral electron disequilibrium starts.

Only a concern for cones < 5mm
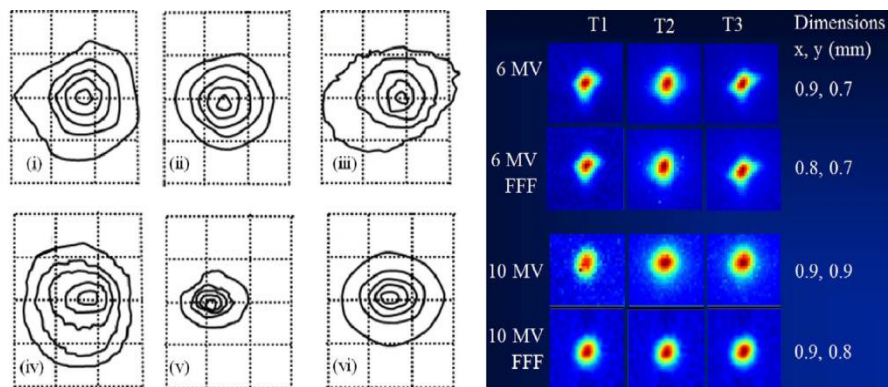
Figure 14: Focal Spot Size in Real Life

7.2.3 Field size definition

The loss of LCPE and source oclusion effect will cause

As the field size goes small the field becomes an overlap of penumbras and the geometric field size and radiation field size (given by the Full Width at Half Maximum) dont match anymore. In Other words, light field size does not match the dosimetric field size.

FWHM is greater than geometric field size for small fields and is the recomended as referencing the field size. This may have an impact on your choice of cone when planning a tiny target for a SRS plan.
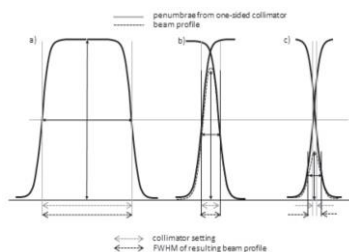
Figure 15: Field size definition

7.2.4 Mismatch of Detector vs field size

- detector-related condition
- when the dose changes across the detector, the signal is subject to volume effect:
  - ✓ Dose in the field is underestimated
  - ✓ Width of the penumbra is overestimated

Another condition for small field size classification is the mismatch of detector and field size.

This is a detector related condition.

If the radiation fluence across the detector volume is not constant, its signal is subject to volume averaging effect.

The direct implication of that is that dose, for small fields, dose in the central axis can be underestimated and the penumbra width can be overestimated. We will see how in the following slides

7.2.5 The volume Effect

Lets say we want to measure the profile of a 1x1cm field size field.

And we have a selection of detectors with diferente dimensions to do so.

Here we can see a comparison of some detector dimensions in scale against a 1x1cm2 field.
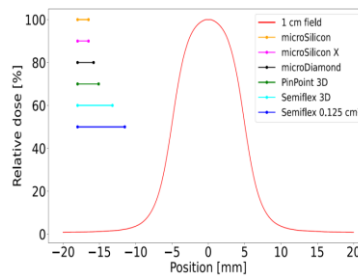
Figure 16: The volume Effect 1

If we use a semiflex 0.125cc chamber against a 1x1cm2 field, it is clear that it is too big to characterize that field.

One can see what the chamber will actually do: it will average the dose across the its sensitive volume. The decreased fluence on the detector borders will under-estimate the dose in the effective point of measurment

The dose in the central axis will be under estimated
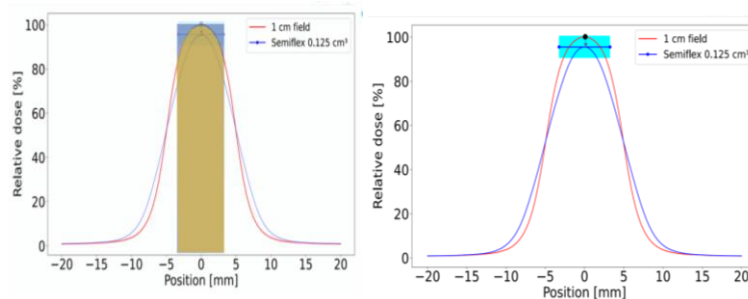
Figure 17: The volume Effect 2

Blue curve show the signal after averaging over the entire volume of the detector.

The central axis dose is underestimated withi the penumbra is broadened
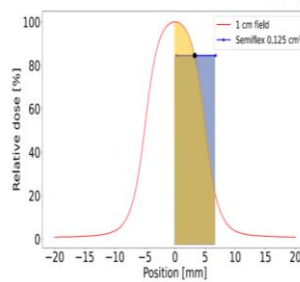
Figure 18: The volume Effect 3

In the penumbra region the measuring looks like that

The detector will measure the signal over a dose gradiente region.

In this particular position, the half of detector inside the field will receive more dose than effective point of measurment but this excess will be over compensated by the decreased fluence in outside part. The detector reading will not reflect properly the dose at the effective point of measurement.
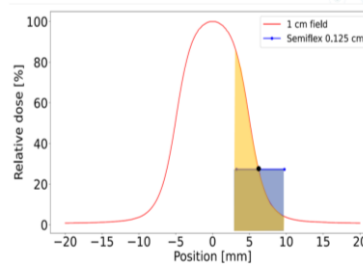
Figure 19: The volume Effect 4

The dose is under-estimated in that point.

In the Other hand, more towards the profile tail

The detector will also measure the signal over a dose gradiente region.

In this particular position, the half of detector inside the field will receive more dose than effective point of measurment and this excessiv will not be sufficiently compensate by the outside part. The detector reading will not reflect properly the dose at the effective point of measurement.

The dose is super-estimated in that point.
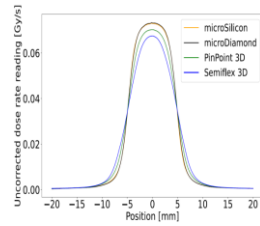
Figure 20: The volume Effect 5

The final result, if the detector presents volume averaging effect, is that the CAX dose is under-estimated and the penumbra is broadened.

The same can happen to the penumbra

7.2.6 Volume effect – normalization issues

Usually, profiles are evaluated after CAX normalization. If you combine CAX normalization with volume effect, out of field dose and FWHM can also be also overestimated
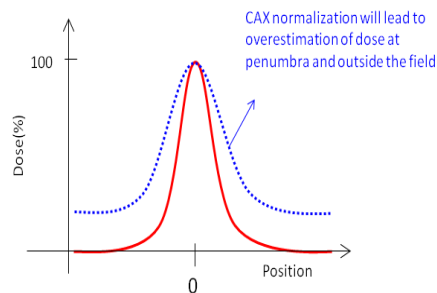
Figure 21: The volume Effect 6

Field penumbra is artificially broadened due to the finite size of the detector. Important when detector is larger than 1/4th of the lateral field dimension.

- ✓ Dose in the center is under-estimated

- ✓ Penumbra appears wider than it is (volume effect)

7.2.7 Volume Averaging Effect (PDD)

For very small fields, be careful on the size of the ion chamber: it can over-respond at depth due to volume averaging pronounced at dmax relative to depth—thus increasing PDD at depth
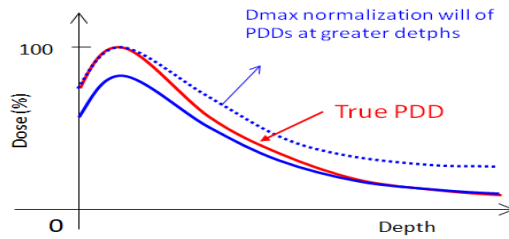
Figure 22: Volume Averaging Effect (PDD) 7

In the same way, the volume effect can affect PDDs measurements.

Due to beam diververgence, the volume effect may be more pronounced close to the surface, reducing the readings. At the depth, the effect becomes less important…

Since, usually PPDs are normalized to dmax, the PDD at depth can be overestimated.

7.2.8   The volume effect (Output Factors)

Here we show the volume averaging effect on Output factors

Uncorrected output factors for smal sq fields. For smaller tha 2x2cm the reduced signal of bigger detectors can be seen

Averaging effect can underestimate your Output factors for small field sizes. Under-estimation in OF leads to overdose of patient
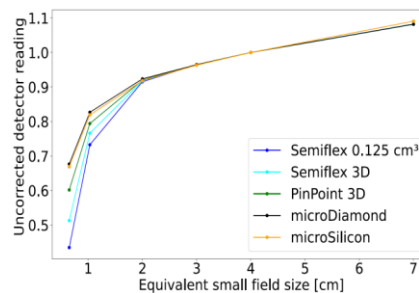
Figure 23: The volume Effect (Output Factors) 8

7.3   TRS 483 Formalism

➢ independent Codes of Practice in one document:

7.3.1   Reference Dosimetry

- Useful for machines that don't satisfy reference conditions:

  ▪ Don't allow a 10x10cm2 field

  ▪ Not possible to setup a phantom at SSD = 80 or 100cm

- For example: Tomotherapy, Cyberknife, GammKnife, cones added to C-arm linacs, add-0n micro-MLC in C-arm linacs

- New concept: machine specific reference field (msr)

- f*msr* is the max field size close to 10x10cm2

- f*msr* is not a small field:

  - equilibrium is needed

  - no source occlusion

  - f*msr* is greater than 2 x r*LCPE* + d

- Similar to TRS 398, introcing the beam quality correction factor

7.3.2 Small Field Dosimetry

- Relative dosimetry

- Output factors

  14.1.1.1Reference dosimetry: determination of Dw

$$D_{W,Q_{msr}}^{f_{msr}} = M_{Q_{msr}}^{f_{msr}} N_{D,W,Q_0}^{f_{ref}} K_{Q_{msr},Q_0}^{f_{msr},f_{ref}} \ldots\ldots(\text{II}.2)$$

$M_{Q_{msr}}^{f_{msr}}$ =Detector reading

$N_{D,W,Q_0}^{f_{ref}}$ =Calibration coefficent

$K_{Q_{msr},Q_0}^{f_{msr},f_{ref}}$ =Beam quality correction fator (tables for each machine)

$k_{Q_{msr},Q_0}^{f_{msr},f_{ref}}$ is the beam quality correction factor that corrects for the use of the calib. coefficient in the fmsr and is machine, beam quality and detector specific

7.3.2.1 Dw in small fields: field output factor

$K_{Q_{msr},Q_0}^{f_{msr},f_{ref}}$ corrects for:

- ✓ The density of the sensitive volume of the detector

- ✓ The atomic properties of the sensitive volume

- ✓ The presence of extracameral components

- ✓ Volume averaging (unflatened beams)
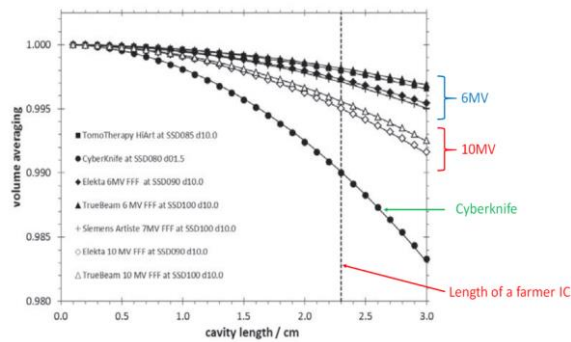
Figure 24: Dw in small fields

Just to illustrate the averaging effect, in this plot we have the volume averaging for different machines in respect to the detector cavity length. We can see that the volume effect is more related to the beam energy, having the machine model a minor effect. The outlier is CK, that has a sharper unflatened beam

Note that the volume averaging always cause an underestimation of the dose in the central axis for FFF beam

So the correction factor for volume averaging in the central axis for FFF beams depends on the beam energy and it is always greater that 1

The bigger the chamber, the greater is the correction factor

$$TPR_{20,10}(10) = \frac{TPR_{20,10}(s) + c(10-S)}{1 + c(10-S)} \ldots\ldots (\text{II} - 3)$$

Where c=$(16.15 \pm 0.12) \times 10^{-3}$, valid for $4 \leq S \leq 12$, S being the equivalent square msr field size in cm

$$\%dd(10,10) = \frac{\%dd(10,S) + 80c(10-S)}{1 + c(10-S)} \ldots\ldots (\text{II} - 4)$$

Where c= $(53.4 \pm 1.1) \times 10^{-3}, valid\ for\ 4 \leq S \leq 12$

To get the TPR20,10(10x10) for a beam from a machine that does not allow 10x10 field size, you need measure TPR20,10 of fmsr and use this expression., Alternatively, you can do the same for PDD10 (10x10)

$$\Omega_{Q_{clin},Q_{msr}}^{f_{clin},f_{msr}} = \frac{M_{Q_{clin}}^{f_{clin}}}{M_{Q_{msr}}^{f_{clin}}} k_{Q_{clin},Q_{msr}}^{f_{clin},f_{msr}} \ldots\ldots\ldots (\text{II} - 5)$$

$\frac{M_{Q_{clin}}^{f_{clin}}}{M_{Q_{msr}}^{f_{msr}}}$ =conventional OF

$K_{Q_{clin},Q_{msr}}^{f_{clin},f_{msr}}$ = is the field output correction factor, i.e., corrects the conventional ratio of detector readings for perturbations that depends on the field size

Note: equivalent square field size. For 6cm diameter cone, you must use the equivalent square field of 5,3cm, for example. There is a table for that! 10 MV table is also available and 10MV is the max energy in TRS 483

7.3.2.2 Corrections for Ionization Chambers

Corrections for IC go up as we decrease the field size, that is because of the air density
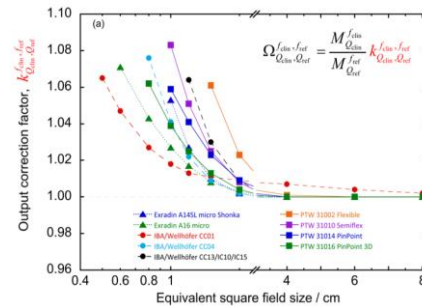
Figure 25: Corrections for Ionization Chambers

7.3.3 Equipments for Relative Dosimetry

    a) No ideal detector exists

    b) be aware of pros and cons

    c) use 2 or 3 different detectors so that redundancy gives confidence

7.3.4 Detectors for Field Output

    a) Choose detectors that don't have corrections factor greater than 5% for your set of measurements (ideally <2%)

    b) Detector orientation

    c) Centering the detector

7.3.5 Relative dosimetry: measurements

    a) Jaws and MLC calibration becomes more critical

    b) It's very important to check field size calibration before starting the beam data acquisition

    c) Reference chamber:

        ✓ if you used, any drift in dose rate will show up as slope the profile or change in PDD shape, even if minor fluctuations are averaged out over each step size.

        ✓ It cannot interfere in the field detector or be interfered by it

✓ Options: transmission chamber; specific slot in linac head to place the chamber.

d) Scanning parameters:

    ✓ Adequate speed to avoid water surface perturbation

    ✓ Sub-millimetric steps (i.e., 0.2mm for FS< 15mm, 0.5mm for FS > 0.5mm)

    ✓ sampling time: long enough to avoid noisy readings

e) Centering the detector

    ✓ Light field just for the initial alignment

    ✓ Inplane/crossplane scanning to find the CAX at measurement depth

- check different depths if measuring PDDs to ensure scanning is to CAX

- scan CAX at every depth every time a profile is done, no matter how good the setup is

f) for MLC shaped fields, perform the alignment procedure and FWHM determination every time the field has been set or re-set by moving the collimator

7.3.6 Relative dosimetry: Centering the detector
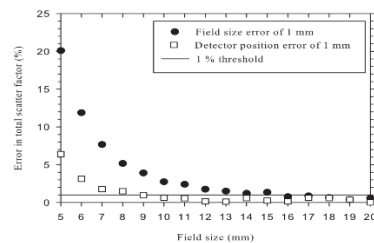
Figure 26: Relative dosimetry

This is to illustrate the impact of detector position and field size (meaning MLC or Jaw accuracy) in the output for small field sizes, specially < 15mm

7.3.7 Relative dosimetry: detector orientation
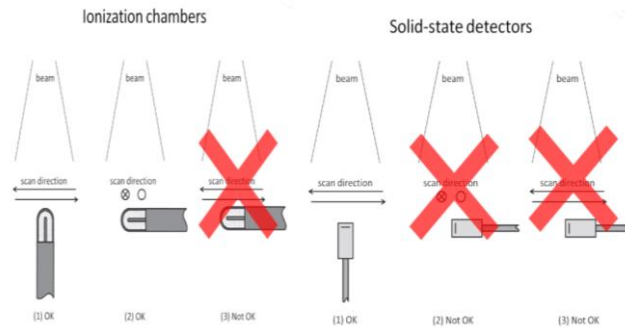
Figure 27: Detector Orientation

7.4 Measuring Small Fields PDDs

Small and very small fields have minimum in-scatter photons, so beam spectrum does not change with depth, thus we can use shielded or unshielded diodes interchangeably

Recommended detectors

1. Unshielded Diode

2. Microdiamond

3. Shielded diode

4. Micro IC: A16, cc01, etc.

For PDDs, as long you have a detector that does not give you volume averaging effect, all detectors should give you similar results
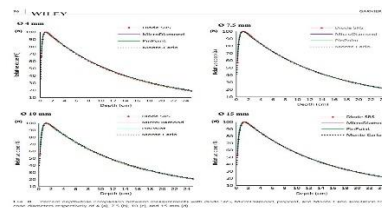
Figure 28: Measuring Small Fields PDDs

VERY important to have your chamber centered on radiation at all depths! This means your radiation beam is perpendicular to your phantom, and your mechanics of the scanning system are parallel to the beam. And that the chamber is centered by radiation profile analysis.

For small fields, in general, the lower the better It means less volume averaging effect
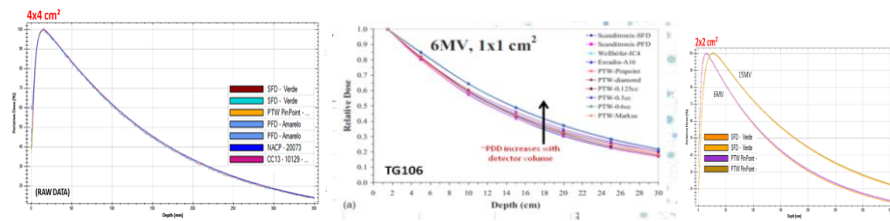
Figure 29: RD=f.Depth (cm)

For this field size, all detectors (from the regular 0.125cm³ IC to the smallest) should give a good response

For small (but not too small field sizes), volume averaging effects are neglegible and energy dependance of detectors due to low energy scattered radiation is minimum. Most of detectors should give similar results

7.5   Reference Applied

If you are familiar with TRS 398, you know that dose determination at reference conditions has to be done in a 10x10cm field size.

How to determine the absorbed dose with a calibrated detector from a primary calibration laboratory for a machine that does not allow 10x10 field size, or it is impossible to setup a phantom with SSD 80 or 100cm? For exemple, Tomotherapy , Cyberknife, Gamma Knife , TRS 483 introduces the concept of machine specific reference field (msr).

Tomotherapy (5x10cm, SSD = 85cm, d = 10cm), CK (circular cone 6cm, SSD = 80cm, d = 10cm), GK (circular cone 1,6 or 1,8cm, SSD = 32, d = 8cm), msr for a conventional C arm linac is a 10x10cm2 , It is important to note that msr is not a small field (there is Lateral Charged-Particle equilibrium, there is no soucer oclusion $k_{Q_{msr},Q_0}^{f_{msr},f_{ref}}$

7.6   Summary

    a)   A small field: LCPE, source occlusion, size of detector vs field size

    b)   TRS 483:

✓ reference dose: machine specific field vs detector size corrections

✓ field output corrections: corrections specific for each specific, field size and detector size

    c)   Small field measurements:

      ✓   Choice of detectors: type of measurement and field size

      ✓   Centering, beam alignment and scanning parameters are crucial

✓ Be aware of volume averaging effects

✓ Compare with other detectors

7.7   Stereotactic Radiosurgery (Commissioning)[11]

The basic principles involved in the commissioning of radiosurgical devices are very similar for all such devices, despite the large variations in dose delivery techniques that they entail.

Four aspects in Commissioning:

➢ SAFETY: To ensure radiation safety and integrity of the patient.

  Example: Interlocks for emergency and collisions.

➢ MECHANICAL: The mechanical integrity of the radiosurgical device must be within acceptable tolerances.

  Example: Isocentricity (Winston-Lutz tests), localization tests.

➢ DOSIMETRY: To provide accurate treatment planning and reliable as well as accurate delivery of the prescribed dose, the properties of radiation beams must be measured.

  Example: PDDs and beam profiles for small field sizes using appropriate ion-chambers (very small active volume) or stereotactic diodes.

➢ VALIDATION (End-to-End QA): All steps involved in the radiosurgical procedure, from the target localization, through treatment planning to dose delivery, must be verified experimentally to ensure reliable and accurate performance of the hardware and software used in the radiosurgical procedure.

➢ QA Team:

Core radiosurgical team -consisting of a neurosurgeon and/or a radiation oncologist, a medical physicist and a radiation therapist- should develop a QA program for SRS/SBRT.

➢ The quality assurance protocols for radiosurgery fall into two categories:

➢ Safety, mechanical, and dosimetry periodic QA protocols (non patient-specific): Cover the performance of all equipment used for target localization, 3-D treatment planning and radiosurgical dose delivery via Daily, Weekly, Monthly, and Yearly tests specified from national standard recommendations (TG-142, etc.)

➢ Patient Specific QA protocol:

➢ The treatment quality assurance protocols dealing with the calibration and preparation of equipment immediately preceding the radiosurgical treatment of a patient.

Example: Collision, isocentricity, and dosimetry checks of specific plan.

➢ Treatment quality assurance during the radiosurgical treatment of the patient. In most centers, physicist is present during treatment, checking setup of the patient and delivery of radiation.

8   RADIOBIOLOGY OF STEREOTACTIC RADIOTHERAPY TECHNIQUES

8.1   Biological actions of ionising radiation[12]

It takes place in four stages:

a) Physical step: ionizing rays act directly on the component's membrane cells.

b) Chemical step: the incident beam and the water contained in the body react. It's radiolysis of water. A chain of biochemical reactions forms toxic products (hydrogen gas and hydrogen peroxide). They damage the DNA that is the main target of the rays Ionizing.

c) Cellular step: The previous steps lead to cellular dysfunction. All unrepaired lesions of the DNA molecule and cellular components result in either mutation or cell death by apoptosis

d) Tissue stage: This results in tissue necrosis. However, cell death is more important in tumor tissue than in healthy tissue after a radiation dose. In Indeed, cells are more radiosensitive during the G2-M phase of the cell cycle. Like tumor cells divide more often than healthy cells, the probability of irradiating A tumor cell in this phase is more important.

Tableau 3: Radiobiology of Stereotactic radiotherapy

Term	Concise Definition	Notes
Stereotactic Body Radiation Therapy (SBRT) = Stereotactic Ablative Radiation Therapy (SAbR)	very high dose, extremely precise, externally-generated ionizing radiation in 5 or fewer treatment fractions	(Stereotactic) – 3- dimensional reference system in many forms, such as body frame with external reference markers, internal fiducial markers, or often in many modern clinics it is CBCT-based localization of tumor volume
Stereotactic Radiosurgery (SRS)	Intracranial equivalent of SBRT in 1 treatment	
Fractionated Stereotactic Radiotherapy (fSRT)	SRS style, intracranial, > 1 fraction	Some use "fSRT" and "SBRT" interchangeable when referring to intracranial 2-5 fraction treatments
Oligometastatic Disease (OMD)	Fewer than 5 known metastatic sites	Not an accepted phenomena for all cancers. Defined number of sites being driven by clinical trials and may change over time

Oligorecurrent Disease (ORD)	Previously non-metastatic patient, not receiving active systemic therapy, developed OMD	
Oligoprogressive Disease (OPD)	Previously non-metastatic patient, not receiving active systemic therapy, developed OMD	
Synchronous OMD	Within 6 months of initial diagnosis	
Metachronous OMD	> 6 months from initial diagnosis	

8.2 Important Definitions

The 5 R's of Tumor Radiobiology – a refresher

    a. Repair of sublethal cellular damage

    b. Repopulation of cells after radiation

    c. Redistribution of cells within the cell cycle

    d. Reoxygenation of the surviving cells

    e. Radiosensitivity (intrinsic)

8.3 SRS/SBRT – Radiobiological Rationale

    a) Modern advanced technology may allow for treatment precision that overcomes situations of concern with normal tissue injury (e.g. clinical risk of ablation of a small volume of lung is extremely low)

    b) Additional indirect antitumor effects may be achieved through SAbR compared to conventional fractionation, such as antitumor immune response and enhanced vascular injury

    c) May overcome issues with reoxygenation, redistribution and repopulation
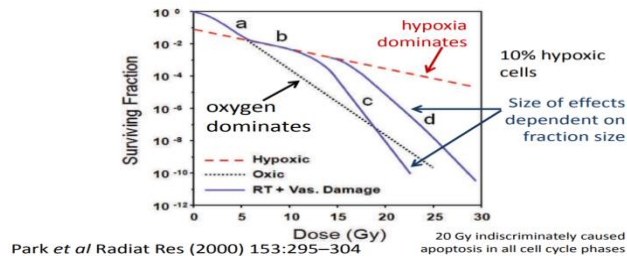
Figure 30: SRS/SBRT – Radiobiological Rationale

8.4 Tissues vary in radio-responsiveness

Eukaryotic Survival Curves are Exponential but have a 'Shoulder' ,(Puck and Marcus. First in vitro mammalian survival curve *JEM* 1956)
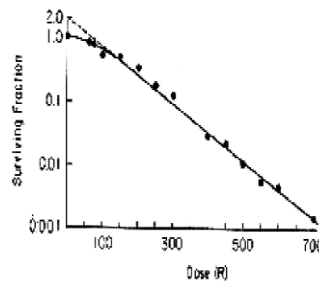
Figure 31: Tissues vary in radio-responsiveness

8.5 Linear Quadratic Model Of Cell Kill

Linear Quadratic equation

$$S = exp[-(\alpha D + \beta D^2)]$$

S = cancer stem cell survival probability at dose D

G = Lea-Catcheside time function (0-1); describes the reduction in effect due to dose protraction

α = the linear term, dose-protraction independent

β = the quadratic term, protraction dependent
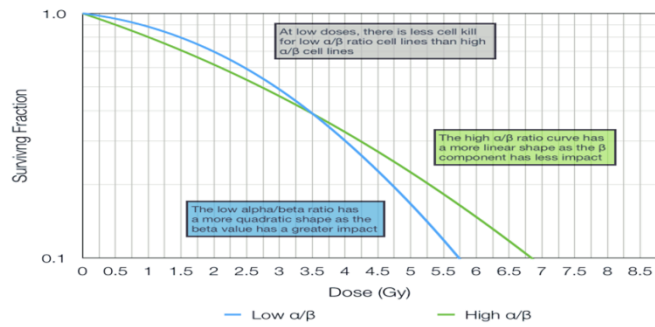
Figure 32: Linear Quadratic Model Of Cell Kill

8.6   Biological Effective Dose (BED)[13]

In a recent editorial , we suggest that dose escalation, not (new biology) can account for the efficacy of SBRT with early-stage NSCLC. We used the term "new biology" to describe any of the above mentioned novel radiobiological mechanisms that could potentially make SBRT more effective than would be predicted from clinical experience with fractionated radiotherapy. Mehta and colleagues recently reviewed the available local control data for early-stage NSCLC patients undergoing 3D-CRT and SBRT. (Imger Ⅰ Ⅰ -3A) shows the NSCLC tumor control probability (TCP) data as a function of BED, replotted in Brown et al. to clearly distinguish the data for single fraction SBRT, multi-fraction SBRT, and conventional 3D-CRT. A monotonic relationship between TCP and BED is clearly observed for the 3D-CRT and SBRT data. Regardless of fractionation, higher TCPs are obtained by delivering higher tumor BEDs. Thus, there is currently no evidence from the available NSCLC data in the literature that SBRT and 3D-CRT produce different probabilities of tumor control when corrected for tumor BED. Based on the observations that TCP increases monotonically with BED, andthe TCP vs. BED relation is similar for 3D-CRT, single-fraction and multi-fraction SBRT, we can say with some confidence that the great success of SBRT is due to the fact that the new stereotactic radiotherapy technologies provide dose distributions that permit the clinician to prescribe BEDs of 100 Gy or more. These high tumor BEDs are simply unachievable with conventional dose delivery techniques. The higher TCPs for SBRT can therefore be fully explained by the much higher tumor doses delivered, and are entirely consistent with predictions of the linear-quadratic model. For non-small cell lung cancer, there is no need to invoke a "new biology" to explain the high cure rates. We have also reached the same conclusions for brain metastases (Brenner et al. 2013, in preparation).

Figure 33: Modeling (using the 5 R's) predicts loss of efficacy of tumor cell kill for the same level of normal tissue toxicity as the dose /fraction increases

Predicted surviving fraction of tumor cells for different size dose fractionations assuming fraction of the tumer , f_{hyp} , is shown . it is evident thet there is less cell kill predicted for very few fractions compared to standard fractionation for the same BED (response of well-oxygenated normal tissues)
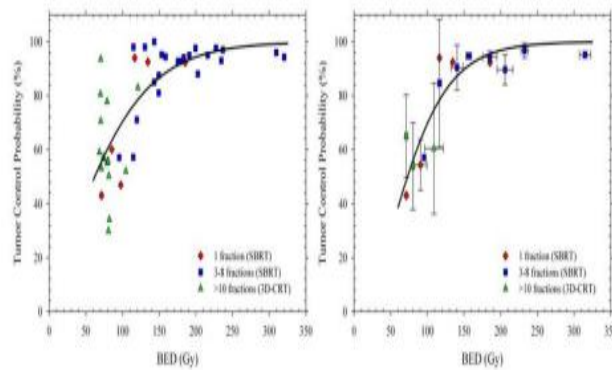
Figure 34: Tumor control probability (TCP) as a function of biologically effective dose (BED) for stage I NSCLC

Right panel : weighted mean TCP probabilities calculated to compensate for the different numbers of patients in each study . Solid lines show LQ based fits to the data which show that, within the limits of clinical data , the limits of clinical data, the efficacy of single doses, a few SBRT fractions , and conventional radiotherapy produce the same overall TCP for the same BED.

Left panel: symbols show local control rates (≥ 2years) from a pooled analysis reported by Mehta. With symbols distinguishing conventional and SBRT fractionations

$$BED = nd \left[1 + \frac{d}{\alpha/\beta}\right]$$

n = number of fractions

d = dose per fraction

8.7   Flaws of the Linear Quadratic Model for SRS/SBRT

    a.   Reaches dose/fraction range where it overestimates cell kill

    b.   Inherently assumes same effect of each fraction delivered

    c.   Implicit in the model is full reoxygenation between each fraction
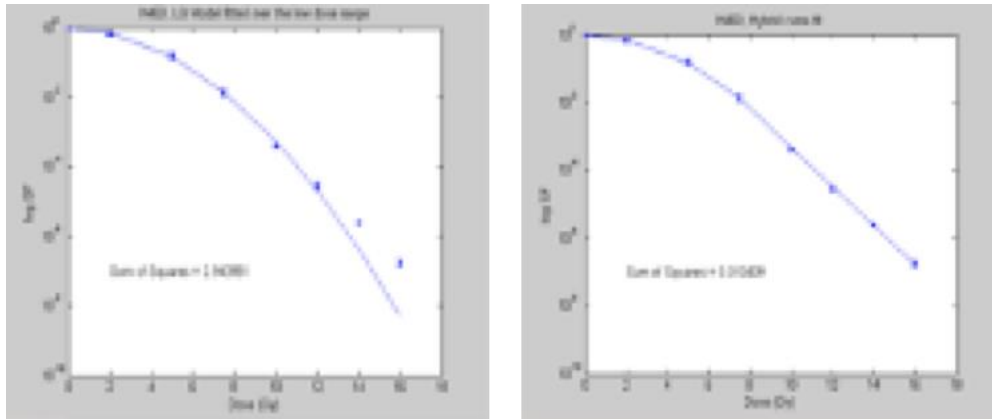
Figure 35: Flaws of the Linear Quadratic Model for SRS/SBRT

➤ SRS/SBRT – Other Radiobiological Models
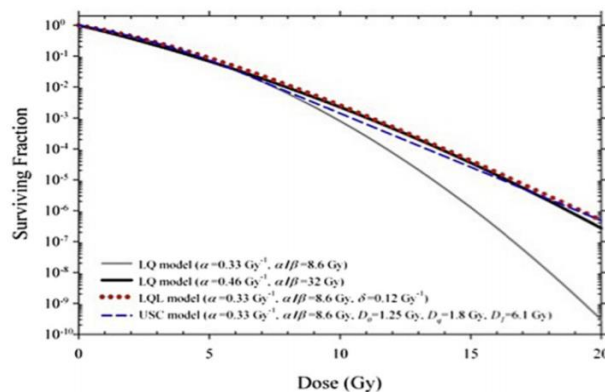
Figure 36: The perceived overprediction of cell killing at high doses by the LQ model

Key messages:

- These models all have flaws

- They are often our only alternatives

- Garbage in = garbage out; continue to read literature as our understanding evolves

8.8   Biological Challenges to the 5 Rs for SRS/SBRT[14]

As noted earlier, there have been several biological effects that suggest that doses per fraction above 10 Gy give greater antitumor efficacy than predicted from standard radiobiological modeling as follow:

8.8.1 Endothelial cell damage may enhance the cytotoxic effect of irradiation on tumor cells

The joint laboratories of Zvi Fuks and Richard Kolesnick published in 2003 an influential paper (and expanded later (30)) proposing that the radiation sensitivity of tumors to dose fractions of 10 Gy or more was governed by the sensitivity of the tumor endothelial cells to apoptosis: the same tumors in mice sensitive to radiation-induced endothelial cell apoptosis were more sensitive to radiation than those in mice resistant to endothelial cell apoptosis (Imager Ⅰ Ⅰ-7A). However, data in the same publication suggests there could be another explanation, namely that the composition of the bone marrow could have affected the radiation response. (Imager Ⅱ-7B) shows that the tumors in wild-type (amase+/+) mice could be converted from sensitive to resistant by a bone marrow transplant from endothelial apoptosis resistant (amase−/−) mice. The authors proposed that the endothelial cells in the bone marrow transplanted mice had derived from the new bone marrow, but more recent studies of others has cast doubt on this possibility , or have suggested that incorporation of bone marrow cells into tumor endothelium is mostly very low . This suggests that it is the asmase−/− character of the bone marrow, not the endothelial cells of the tumor, that is responsible for the tumor resistance in this model.

Another challenge to the endothelial cell apoptosis theory is that no other lab has independently confirmed the data, rather, most publications have shown only modest changes to the vasculature with a gradual loss of tumor endothelial cells after irradiation . We therefore conclude that without further confirmation the concept that rapid post-irradiation endothelial damage amplifies tumor cell kill may not be generally applicable to SBRT.
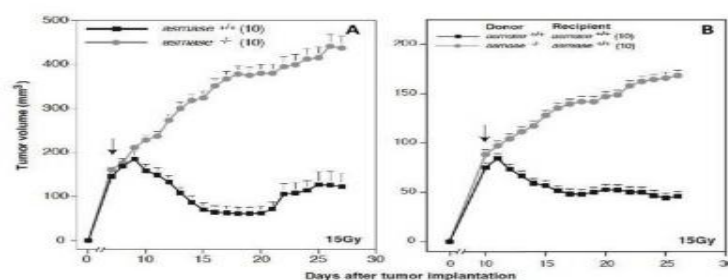
Figure 37: Tumor response is affected by genetics

8.8.2 Vascular Damage at High Doses Produces Secondary Cell Killing

This theory, suggested by Song and colleagues, suggests that radiation doses higher than about 10 Gy induce vascular damage leading to indirect tumor cell death. The concept is illustrated in (Imager (Ⅱ-8)) . Though this is an attractive hypothesis there are only fragmentary data to

support it (Imager (Ⅱ-8)). There are also extensive early data from Barendsen and Broese on the survival of cells in a rat rhabdomyosarcoma as a function of time after single doses of both 10 and 20 Gy that shows no evidence of this increasing cell kill as a function of time after irradiation (Imager (Ⅱ-8)). We thus conclude that there needs to be considerable more experimental evidence that this potential mechanism plays a role in the sensitivity of tumors after high dose per fraction radiotherapy
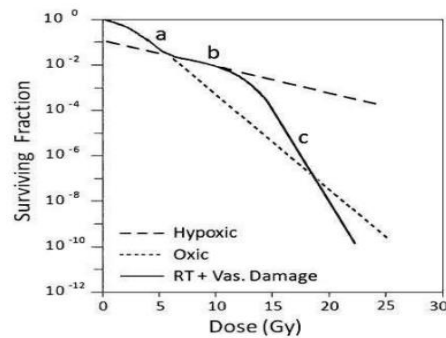
Figure 38: An illustration of how indirect death due to vascular damage could contribute to total clonogenic cell kill in tumors irradiated with large single doses of radiation

8.8.3   Enhanced antitumor immunity after tumor irradiation

There is now clinical evidence that for melanoma, irradiation by SBRT of a tumor at one site contributes to an antitumor immunological rejection of a metastatic lesion at a distant site- a so-called (abscopal effect) . So far the data have been reported for only two patients so there are many questions to be resolved. These include whether this phenomenon is produced only at high single doses (or high doses per fraction), and whether other tumors besides melanoma experience this effect. On the first of these questions the preclinical data suggest that though radiation enhances the antigenicity of tumors it has been reported by the Demaria lab that this is greater for fractionated irradiation than for single doses .

However, none of the radiation schedules tested in this study was comparable to standard fractionation: of the schedules tested (20 Gy ×1, 8 Gy ×3, and 6 Gy ×5 fractions in consecutive days), The fractionated 8 Gy was the most effective with the 6 Gy intermediate and the 20 Gy the least effective. Thus all of these schedules could be considered to be similar to SBRT. Another preclinical study from the Weichselbaum laboratory has reported a similar enhancement of antitumor immunity by local tumor irradiation but in this case there was a greater effect of 20 Gy ×1 than 5 Gy ×4 over 2 weeks. Of interest is that the Demaria study in mice and in the clinical study with melanoma mentioned above the radiation was combined with anti-CTLA-4 antibody: in the case of the preclinical study there was no indication of enhanced antitumor immunity by

the radiation alone though in the Weichselbaum study antitumor immunity was achieved by irradiation alone.

These data are clearly exciting and illustrate the fact that much more information is needed in this field to be able to recommend the best doses per fraction and timing of the radiation regimen to optimize this effect. Also of major importance is just how general the phenomena of enhanced antitumor immunity by high dose/fraction radiotherapy will be across the spectrum of tumors undergoing radiotherapy.

8.9 Preclinical data with tumors do not support enhanced efficacy of high dose radiation

A number of investigators have addressed the question of whether tumor control at high single doses can be predicted from in vitro survival curves obtained at low doses. In general, these have been successful – i.e. the dose to control 50% of the tumors (TCD50) is consistent with the sensitivity of the tumor cells determined at low to moderate doses. The most compelling of these data are from the laboratory of Gerweck who determined the in vitro sensitivity of six tumor cell lines, as well as the number of cells needed to transplant the tumors (TD50) and showed that these two parameters could predict the in vivo TCD50 (Imager Ⅱ-9). Importantly four of the six tumors were from tumors that had originated spontaneously in mice and were transplanted into their respective hosts. Thus, an immunological component could have been involved. The other two were human tumors transplanted into nude mice. These data demonstrating that the TCD50 to large single doses (>20 Gy) can be predicted from the radiation survival curve at low doses (<10Gy) , do not support any extra cell kill due to endothelial damage, vascular collapse or enhanced immunity.
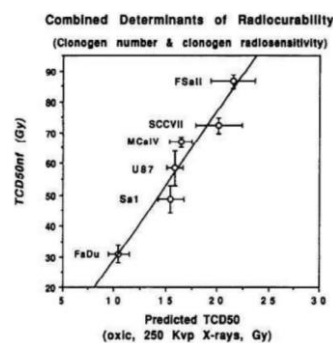
Figure 39: The radiation dose to control 50% of the tumors (TCD50) is well predicted from the radiosensitivity of the cells in vitro and the number of cells needed to transplant the tumor (TD50)

Clinical Data Suggest that Radiobiological Modeling with the Linear Quadratic Equation is Adequate to Explain the Efficacy of SRS and SBRT [15]

In a recent editorial, we suggest that dose escalation, not (new biology) can account for the efficacy of SBRT with early-stage NSCLC. We used the term "new biology" to describe any of the above mentioned novel radiobiological mechanisms that could potentially make SBRT more effective than would be predicted from clinical experience with fractionated radiotherapy. Mehta and colleagues recently reviewed the available local control data for early-stage NSCLC patients undergoing 3D-CRT and SBRT. (Fig 8A) shows the NSCLC tumor control probability (TCP) data as a function of BED, replotted in Brown et al. to clearly distinguish the data for single fraction SBRT, multi-fraction SBRT, and conventional 3D-CRT. A monotonic relationship between TCP and BED is clearly observed for the 3D-CRT and SBRT data. Regardless of fractionation, higher TCPs are obtained by delivering higher tumor BEDs. Thus, there is currently no evidence from the available NSCLC data in the literature that SBRT and 3D-CRT produce different probabilities of tumor control when corrected for tumor BED. Based on the observations that TCP increases monotonically with BED, and the TCP vs. BED relation is similar for 3D-CRT, single-fraction and multi-fraction SBRT, we can say with some confidence that the great success of SBRT is due to the fact that the new stereotactic radiotherapy technologies provide dose distributions that permit the clinician to prescribe BEDs of 100 Gy or more. These high tumor BEDs are simply unachievable with conventional dose delivery techniques. The higher TCPs for SBRT can therefore be fully explained by the much higher tumor doses delivered, and are entirely consistent with predictions of the linear-quadratic model. For non-small cell lung cancer, there is no need to invoke a "new biology" to explain the high cure rates. We have also reached the same conclusions for brain metastases (Brenner et al. 2013, in preparation).

9   <u>CLINICAL FUNDAMENTALS</u> [16]

9.1   Clinical Concepts

a) Normal tissue dosimetric constraints continue to evolve. AAPM TG101 was a start, but many of those numbers have changed

b) Tumor control probability estimates continue to evolve as patients live longer, particularly relevant in the metastatic population

c) Effective local therapy may make oligometastatic or oligoprogressive patients live longer

d) "Ablative" doses impart higher risk of treatment with each fraction – patients can get hurt if mistakes are made

e) Like with conventional fractionation, some normal tissue types demonstrate recovery between treatment courses, and some don't

9.2   Treatment Delivery Principles

a) Secure immobilization avoiding patient movement for the typical long treatment sessions

b) Accurate repositioning from simulation to treatment

c) Minimization of normal tissue exposure attained by using multiple (e.g., 10 or more) or large-angle arcing small aperture fields

d) Rigorous accounting of organ motion

e) Stereotactic registration (i.e., via fiducial markers or surrogates) of tumor targets and normal tissue avoidance structures to the treatment delivery machine; and Ablative dose fractionation delivered to the patient with subcentimeter accuracy.

f) Prescriptions to low isodose lines (i.e. allowing hotspots of 30-40% on VMAT) are often advantageous on conformality

9.3   Physiology and Pathophysiology, as applied to SBRT /SRS[17]

More than just *serial* or *parallel*

9.3.1   Serial organ (e.g. spinal cord)

a) High dose region. Loss of function distally

b) Toxicity is mostly dose related, but also potentially relevant are:

     i. Length irradiated

ii.   Lateral cross-section irradiated

iii.   Previous irradiation

iv.   Region irradiated (e.g. lateral vs central)

v.   Dose rate

9.3.2   Parallel organ (e.g. peripheral lung, peripheral liver, peripheral kidney)

a)   High dose region. Independent redundancy maintains function elsewhere

b)   Toxicity is mostly volume related

9.4   Simulation and Registration for SBRT/SRS : Motion Management[18]

9.4.1   Refers to internal motion of organs

a)   Lung – most obvious one

b)   Liver

c)   Pancreas

d)   Kidneys

9.4.2   We Do bother to manage motion

We bother to manage motion because

−   Accurate delineation of tumor edges

−   Accurate delineation of OAR

→   A factor in better treatment

➢   Motion Management is used for: All moving tumors, regardless of treatment technique

➢   If you are treating with 3DCRT, IMRT or SBRT, your PTV will be inaccurate if you don't take the motion into account.

➢   Advances in CT scanners, i.e. fast scan times, makes the motion artifacts even worse.

9.5   Recommended Motion Management techniques

Motion-encompassing methods:

a.   ITV created from full phases of a 4DCT scan

b.   Motion capturing device is placed on top of the patient

Place as close to the tumor location as possible, with the most observed motion into indicate the location of the device anatomically or by skin marks

    c.   CT-sim, preferred 10 phases.

    d.   Motion is constructed from full breathing phases

    e.   Target motion path is created from all phases and termed Internal Target Volume (ITV)

ITV: The volume that encompass the motion of the

    f.   Can be used for all tumors (not just lung)

9.6 Considerations for CT-sim

9.6.1 Patient immobilization:

    a)   Many options in the market

    b)   Whatever you chose, proper use is the key.

    c)   Arms resting on arm rest, if patient cannot stretch arms to reach the arm-rest, add a wedge.

    d)   Arms hanging in air do not immobilize properly.

➢ They affect upper body roll.

Knee sponge is a must, use the one with a slot for each knee.

Figure 40: They affect upper body roll

➢ Knee sponges immobilizes gross <u>rotation in the pelvis.</u>

Figure 41: Knee sponges immobilizes gross

➢ Patient is aligned straight on the table.

    ✓   Sagittal (ceiling) laser, bisects the patient.

➢ Conform the vac-lock (blue cushion) to patient's contours, make sure it reaches the mid-axilla line t<u>o prevent roll.</u>

➢ If possible, to have also definition between the thighs.

9.7   Patient Immobilization:

➢ For upper spine, head and neck or any SBRT treatment in the chest area, use a 5-point mask (head and shoulder mask)

➢ Crucial to control neck/chin position <u>to prevent pitch.</u>

   ✓ Assure that chin is well defined in the mask, and neck is sitting comfortably on the neck rest.

   ✓ Don't use neck rests that are old or worn out.

   ✓ Best practice is create a patient-specific cushion for the head and neck region.

Figure 42: Mask of Head and Neck

A primary function of all immobilization devices specifically for SBRT is to prevent non-linear movements, fancy word for rotational movements!

There are 3 different types of rotations:

1. Roll: Very common.

   Happens when one side of the body is higher/lower than the other side. The body rotates as if to one side. Roll can be specific to one region, pelvis only, or abdomen only depending on which part is not immobilized properly.

2. Rotation: Very common

Happens if patient's body is not aligned straight with the sagittal laser. It could also affect only a small region such as the neck.

3. Pitch: Common in brain and upper neck.

Happens when the superior or inferior part of the body is lower/higher than the other. Example: patient's chin is lower/higher than supposed to be, then head has pitch.

➢ CT slice thickness: 2.5mm for SBRT is reasonable. Can go higher resolution, i.e. 2mm.

9.8   Preparing/Coaching the patient

   Motion study for gating, and gated delivery on the linac requires staff efforts and machine (CT and linac) time.

Proper selection of patients is crucial.

Three stop gates:

A. Physician assessment in the clinic. Explain procedure and what is expected and give reading material. Role for nurse educators.

B. CT-sim RTTs: Re-assess and explain patient active role in proper scan.

C. Physicist: Observe breathing pattern for 2-3 minutes, coach the patient if needed. Scanning for a 10 phase cycle takes few minutes. Observe any changes in the breathing wave.

D. During motion study: Assess phase error. 50% phase should be with least amount of artifact compared to other phase. 40%-60% phases should be the (cleanest).

➢ During the motion study, the physicist HAS to be present and attentive.

➢ Don't ask others to attend the 4DCT scan and then you sit in your office and crunch numbers.

➢ The quality of the breathing pattern and patient willingness and cooperation, are more important than the numbers you get from the study.

➢ If the patient cannot keep a regular breathing during the few minutes of a 4DCT study then they cannot maintain a regular breathing during the much longer treatment.

➢ Perform the study, then recommend no gating give reasons. Explore other options of motion management is available. If nothing works for the patient, then SBRT is not the technique of choice.

> Treatment based on gating : Requires special tools in CT-sim and linac rooms, care with placement on patient, especial software and

E. Breath-holds:

✓ Deep Inspiration (DIBH) or Deep exhalation

✓ Patient is CT-simmed with their breath held. It can either be at inspiration or exhalation.

✓ Have the patient practice breath holds. Try to hold breath for at least 20 seconds.

F. Observation:

For DIBH, some patients were observed to 'arc' their back when taking the deep breath. This arcing will be different on different days and will cause many issues on the treatment table to difficult localization.

> Coach the patients and ask them to practice taking the breath hold without any tension in their back muscles.

> Perform 2 practice runs in breath hold with the patient. Make sure the patient can hold for 20 s minimum.

> Height of breath-hold from the peak (or valley) of the patient's breathing cycle.

> Create a 5mm window width and place it where the patient breath-hold was.

> Perform one more practice to make sure that the breath-hold occurs within the window – adjust if needed.

> Don't exhaust the patient. Give them time to catch breath
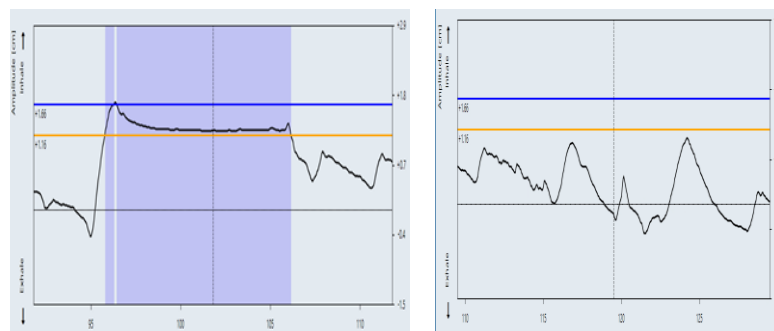
Figure 43: DIBH

❖ Summary

a) Inform the patient that the next breath-hold is the last one, CT-scan will be done.

b) Emphasize that they need to hold their breath within the window as explained earlier.

c) Make sure that they can watch the feedback screen comfortably during the scan.

d) No such things was observed for the exhalation breath hold.

e) Breath-hold can be done without visual feedback screen. However, with no cue for the patient to follow there will be many interruptions during the treatment. The beam will go off when the signal go below the window level. This is especially true for DIBH.

f) Expiration breath hold is less sensitive to visual feedback

9.8.1 Forced shallow-breathing methods:

- ✓ Chest compression

- ✓ Active Breathing Control (ABC - Elekta)

9.8.2 Breath hold – maximum expiration (exhalation)

Every person can breath out to the same level ,we breath out until the lungs run out of air! Perform CT-sim and treatment and DEBH (Deep expiration breath hold). This doesn't require a feedback screen.

9.8.3 Respiration-synchronized technique:

- ✓ Accuray Cyberknife

- ✓ We will go through the practical/clinical issues of each motion management technique, except the one related to Cyberknife

    - ❖ Summary

        a. Motion management is a must for SBRT program

        - Choose the type that best fit with your patient population

        - Allow for patient-specific variations of motion management. One size doesn't fit all.

        - If need be, and if a patient is not a candidate for any type of motion management, then SBRT may not be feasible.

        - Create department protocols that covers the applications of MM.

        b. From CT-sim to Treatment: All about images

        - Considerations for CT-simulation

        - Images for planning

9.9 Contouring SBRT/SRS

Generally the protocole contouring into SBRT/SRS techniques radiotherapy   In many cases, CTV is kept the same as GTV   because to be therapy a small volume , Standard approaches to areas at risk for microscopic disease do not apply   . Expansion of CTV to PTV depends on the correction utilized for tumor motion management (0 to 5mm)

$$\left\{ \begin{array}{l} \text{SRT No CTV} \\ \\ \text{PTV=GTV+iGTV} \end{array} \right.$$

PTV margins still dependent on your comfort with setup & motion errors

> Importance to contour all targets and organs at risk (OARs)

9.9.1 Spine SBRT - Contouring[19]

9.9.1.1 Target Definition:

GTV: MR-guided gross tumour volume

CTV: GTV + margin to account for micro-and macroscopic disease

PTV: 2mm uniform expansion around CTV Potential

9.9.1.2 OARs Contouring:

Spinal cord, thecal sac, cauda, esophagus, stomach, trachea, bowel, lungs, liver, kidneys and other normal structures within the planes of the treatment volume

9.9.2 Prostate SBRT –Contouring[20]

9.9.2.1 Target Definition

- GTV_3625: Prostate only on MR and confirmed on CT
- CTV _3625: Prostate +/- 10mm proximal seminal vesicles (must contour 1cm proximal seminal vesicles as a separate structure (SemVes_Prox) if treated and on trial)
- PTV_3625: 5mm expansion of CTV_3625, except 3mm post.

9.9.2.2 OARs Contouring

External, seeds, Femur_L and Femur_R, Femurs, Bladder, treatment couch Seminal Vesicles, Rectum (from anus to rectosigmoid junction), PenileBulb, Urethra

9.9.3 Contours by planner

9.9.3.1 E-PTV-OAR (tissue within the skin and outside all listed critical normal structures and PTVs)

9.9.4 Brain Metastases Fractionated SBRT/SRS Contouring[21]

9.9.4.1 Target Definition

- GTVs contoured on Gd-enhanced T1-weighted MRI
- GTVs are labelled as GTVx_dose, where x is the course number and   dose is the prescription dose in cGy
- PTVx_dose = GTVx_dose + 3 mm uniform margin

9.9.4.2 OARs Contouring

BrainStem, Chiasm, SpinalCord , External, Eye_L, Eye_R, Lens_L, Lens_R, OpticNerve_L, OpticNerve_R, Brain

9.9.4.3 Contours by Treatment Planner:

Lacrimal Gland L, Lacrimal Gland R

9.9.4.4 VOIs

- − PTV1 =dose + 1 cm
- − PTV2 =dose + 2 cm

Isodose contours for the prescription and ½ of the prescription

9.9.4.5 PRVs:

Apply 3 mm margin to spinal cord, brainstem, chiasm, each optic nerve, brainstem, and any OAR likely to receive close to its tolerance dose

9.10   SBRT lung CT-sim and Contouring[22]

Capturing the breathing motion of the patient and correlating the motion of the tumor inside.

9.10.1 RPM system

Box with reflective dots placed on patient's body. An IR camera records the movement

9.10.2 Bellow belt system

A belt that expands and contracts as the patient moves, is placed around the patient Regardless of the range of motion, the ITV concept will assure that the treatment does not miss the target .

ITV volume = GTV in each breathing phase

Figure 44: ITV Volume

The tumor is most stationary at max exhale, this is Phase 50% , Phases around the max inhalation.

9.10.3 Reasons

a) We don't breath to the same level every time.

b) Mixed chest and abdominal breathing

c) In the CT-sim console. Create an average scan and send it to TPS for planning.

(e .x) For lung: PTV = ITV + 5mm

d) From the linac side: Nothing special. Patient is positioned and setup and asked to breath normally while radiation delivery commences.

e) If the tumor is moving a lot and I used ITV for the full motion.

- ITV encompassing the full range of motion will assure that you don't miss the target.

- PTV volume will be slightly less than the volume created conventionally, however way more than if motion was restricted (by other methods).

- The maximum is recommended motion range for tumor : Keep motion $\leq$ 5mm

The control motion by :

a) Gating

b) Breath Hold

c) Chest compression

d) Tracking

Respiratory gating:

a) Phase gating

b) ITV created from certain phases of a 4DCT scan

c) Start with a 4DCT scan to perform a motion study.

d) Take the 50% phase and use the tumor location as the baseline to check range of motion.
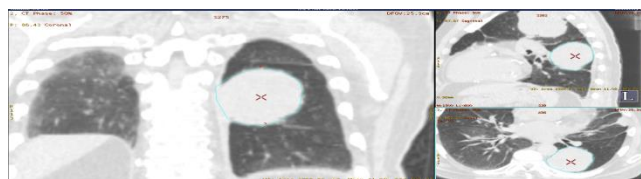
Imager (II -18): Respiratory gating

e) Start with "motion study", to see how much the tumor moves.

f) Take the 50% phase and use the tumor location as the baseline to check range of motion.

g) From the study, find the phases in which motion is $\leq$ 5mm.

h) Create ITV from these phases only.

i) Create average scan from these phases and send to TPS for planning.

11.4.1   The good motion study is :

- The one with the least motion artifacts. If 50% phase has motion artifacts, then it is a good idea to re-do the 4DCT scan. Coaching the patient and assuring that they breath normally.

- 11.4.6 The motion study cann't be done if :

a. Patient was selected for motion management by physician, however …

b. Patient was incapable of keeping a steady breathing. Took a long time on the CT-sim, couldn't get proper scan (scan with minimal motion artifacts)

c. Even though an assessment was made, the physicist recommended not to use gating.

d. Patient was not a candidate for chest wall compression nor DIBH either.

e. Management changed from SBRT to 3DCRT. With ITV of full phases used.

f. The system first has to 'learn' the breathing cycle; Time of exhale and time of inhale.

g. It then predicts the sinusoidal shape of the breathing wave.

h. If the actual breathing wave (solid lines) agrees with the predicted one (white dots), then the computer can generate the scans with minimal motion artifact.

i.   The beam ON/OFF on the treatment machine depends on the patient keeping a predictable breathing pattern. Out of phase treatment might be a mis-administration

j. if a patient requires a contrast AND motion management Choose a form of motion management that allows for contrast to be delivered at the same time.

12. Dosimetry   SBRT/SRS

A. If there is only one CT scan.

    a) One scan for motion management indicates that either chest compression or DIBH were used.

    b) Push the scan to the TPS and start planning

B. 4DCT scan:

    a) Create an average scan from the phases you want to use.

    Average scan may be named as Mean scan or Mean Intensity Projection (Mean IP)

    b) For lung, create a maximum intensity projection, (MIP)

    c) Push the Average and the MIP scan to the planning system. Some clinicians also like to have the full 4DCT scan pushed to verify tumor motion.

    d) Tumor delineation is done on the MIP.

    e) OAR delineation and treatment planning is done on the Average scan.

C. 4DCT with contrast

- Push the Avg and the contrast scan to the planning system.
- Tumor delineation is done on the contrast scan, while OAR and planning is done on the avg scan.

D. Images for Planning
- PET for lung
- MRI for prostate

E. Lava and water scans for fiducial to prostate SBRT requires fiducials.

    ➢ T2 cube for prostate contouring Word of wisdom:

Even if fiducials are present, when you are registering the T2 images with the CT, use the prostate (and not the fiducials) for registration. The urethra is the organ of interest to be delineated as accurately as possible.

a) MR for spine

    ➢ T2 for cord (the CSF will be white).

    ➢ T1 contrast for lesions

    ➢ 1mm axial cuts through the area of interest

12.1 TPS Calculation

The term treatment planning is often used in a restrictive manner to refer only to the production of isodose distributions associated with the choice of a treatment plan (dose planning). However, it is also used to describe the whole technical process, from patient data acquisition to treatment verification. It is this second definition that is used here. Commercially available stereotactic planning systems are often associated with combined neurosurgery, brachytherapy and radiosurgery packages. However, conventional radiotherapy planning systems increasingly offer an optional stereotactic module. The ability of a planning computer to overlay or register images from various modalities such as x-ray CT, MRI, and PET is highly desirable. With MRI becoming an essential imaging tool for the brain, distortion-corrected image registration software is very important in high-precision stereotactic planning. X-ray CT scans represent the distortion-free anatomical baseline against which other modality images are co-registered and potentially fused

Real-time manipulation of the virtual patient, showing the juxtaposition of the target volume and sensitive structures, has become essential for SRT planning. Beam optimisation software is ever more important as the complexity of sensitive structure avoidance makes intuitive planning more difficult. Plan analysis tools for the rapid calculation of dose-volume data and assessment of optimised cost functions are therefore also required. Stereotactic treatment planning not only requires the facility to plan multiple noncoplanar arcs focused to a single or several isocentres, but also to plan using multiple fixed noncoplanar conformal beams defined by either conformal blocking or multileaf collimators (MLCs). shows some of the main planning options available for different target geometries. Tumours with concavities wrapped around sensitives tructures, such as the brain stem and optic apparatus, lend themselves to treatments using IMRT

Tableau 4: Treatment Planning Options for Brain Lesions Using Linac-Based Stereotactic Radiotherapy

Lesion Shape	Treatment Planning Options	Planning Time (h)	Treatment Time (min)
Small sphere (up to 3 cm diameter)	4–6 multiple noncoplanar arcs, single isocentre. Single tertiary collimator	1	30
Large sphere (3–5 cm diameter)	2–4 multiple noncoplanar arcs, single isocentre. Single tertiary collimator	1	15 –30
Ellipsoidal	6 multiple noncoplanar arcs, single isocentre, to include some shorter arc lengths with 1 or 2 collimator changes	3	30–45
Ellipsoidal	Double/triple isocentrer, 2–4 arcs per isocentre, 0–2 collimator changes. Up to 50% higher hot spot	4	45–75
Ellipsoidal	Single isocentre, one tertiary collimator plus secondary jaw adjustments, 3–4 arcs	4	30
Ellipsoidal	4–6 fixed, noncoplanar fields using either blocks or multileaf collimation	4	15–30
Irregularly shaped with semi-enclosed sensitive structure	3–5 isocentres, 2–3 arcs per isocentre, evenly separated arc planes. Up to 50% increase in hotspot doses relative to prescription isodose surface. Up to 3 different circular collimators	6	30–60
Irregularly shaped with semi-enclosed sensitive structure	4–6 fixed, noncoplanar fields using either conformal blocks or micro-leaf collimation. Limited scope for structure avoidance	6	15–30
Irregularly shaped with semi-enclosed sensitive structure	Conformal, dynamic arcing with micro-leaf collimator, 2–4 noncoplanar arcs (Grebe et al. 2001)	6	15–45
Irregularly shaped with semi-enclosed sensitive structure	3–9 fixed field, coplanar IMRT using step and shoot or dynamic mMLCa	8–16	15–45
Irregularly shaped with semi-enclosed sensitive structure	4–9 fixed field, noncoplanar IMRT using step and shoot or dynamic mMLCa	8–16	15–60

9.11 Beam Data Measurement

The measurement of beam data for small, tertiary collimated, megavoltage photon beams typically involves up to five profiles (OARs), a central axis depth dose or TMR curve, output factors, often both in air and water, and build-up curves . A potential lack of lateral electronic equilibrium with these pencil beams requires small detectors having high spatial resolution.

Profiles are therefore commonly measured with x-ray verification film, such as Kodak XV2 or EDR , corrected for any dose/density nonlinearity
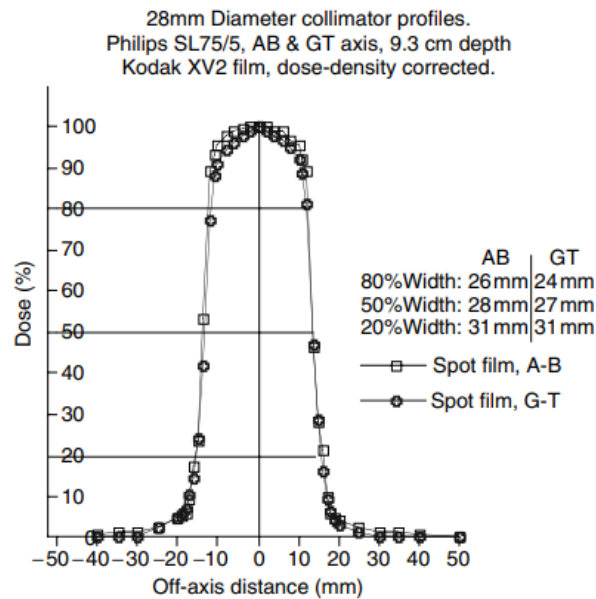
Figure 45: Profiles for a 28 mm diameter collimator at 93 mm depth from kodak XV2 spot film , scanned across the AB (transverse) and GT (longitudinal) directions

Small-volume ($!0.2$ cm3) ionisation chambers are generally suitable for the depth-dose or TMR data down to 20 mm diameter fields. It is important to be aware of the diverging beam for depth-dose measurements of pencil beams, where the detector is exposed to different regions of the beam profile with depth. This could significantly distort the depth-dose curves for small fields. A computerised plotting tank system used in conjunction with a p-type electron diode or diamond detector (McKerracher and Thwaites 1999) is also an ideal means of acquiring these data down to about 15 mm diameter collimators. The setup for such measurements should ideally reflect the mean isocentre depth and scatter geometry of the patient. However, as with all beam data, measurements are often a compromise dictated by the needs of the treatment planning system and the size of the tank available. The smallest beams, below 20 mm diameter, for instance, should be measured with film, TLDs and a small diode, where the detector resolution is in the region of 2 mm or less. Overlap with the larger field sizes is recommended for such work so that discontinuities in data, such as output factors, can be investigated and reconciled. Note that tertiary collimators can also give rise to varying build-up depths to the peak dose.

Generally on dosimetry TPS SBRT/SRS   we take into account the following data :

a) Technique:

✓ VMAT with 0.2 cm calc grid, 4 arcs, 3 non-coplanar (Link

✓ Gamma knife

✓ Cyber Knife

b) Calculation:

Ray tracing (Monte Carlo at discretion of tmt planner)

c) Isocenter Trt:

Isocenter must be no more than≤ 5 cm from the center of any GTV , Tolerance doses for w Rx tolerance doses:

GTV: D100% ≥ Rx dose (D98% ≥ Rx dose is acceptable)

PTV: Dmax = 125% Rx dose (< 140% Rx dose is acceptable)

PTV: D100% > 75% of Rx dose hich PTV coverage must be Compromised

d) Planning Goals:

➢ Brain

- 50% of prescription dose to be within 1 cm of PTV
- 30% of prescription dose to be within 2 cm of PTV

➢ Body

- 50% of prescription dose to be within 2 cm of PTV
- 30% of prescription dose to be within 1 cm of PTV

e) OAR tolerance doses:

As per @Timmerman SBRT dose constraints: Sem Rad Onc, v18(4),   2008,p.215-222

9.12   Beam characteristics

a) Addition of more beams (including non-coplanar – for Brain cases) can help to increase the dose gradient at the boundary of PTV

b) Use of Flattening Filter-Free (FFF) beams

- Higher Dose Rate

- Reduction of treatment time → helps to avoid motion during treatment

c) Jaw opening are twice as much when compared to collimator at 0° or 90°

d) More leakage dose in Superior and inferior beyond PTV

e) Leaves parked inside jaws when unused for RapidArc
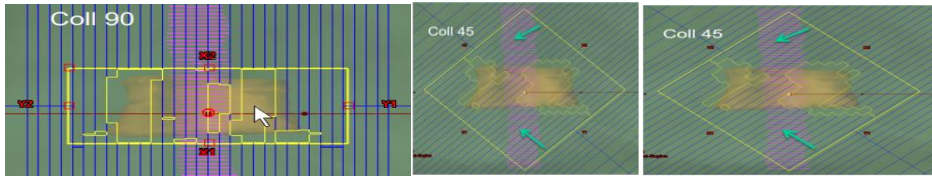
Imager (Ⅱ -20): collimator

9.12.1 In the Margins (5-6mm)

a) If beam margin is close to beam penumbra (5-6 mm)

✓ Homogeneous PTV dose

✓ Maximum dose about 110% of prescription dose

b) Dose fall-off outside PTV is slow
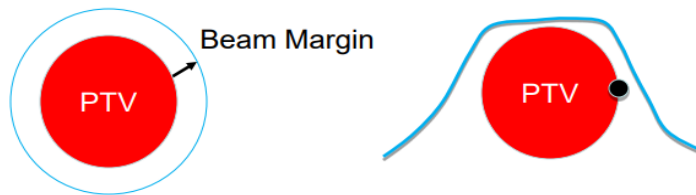
Figure 46: The margins (5-6mm) of PTV

9.12.2 In the Margins (0-2 mm)

a) If beam margin is much less than the penumbra (0-2 mm)

✓ Inhomogeneous PTV dose

✓ Maximum dose ~ 125% or more of prescription dose

b) Dose fall-off outside PTV is fast

Figure 47: The margins (0-2mm) of PTV

9.13   Dose Calculations

a) In SBRT/SRS planning, large dose gradients exist within the PTV to allows for rapid dose fall-off outside the PTV, sparing normal tissues

b) Dose calculation using small dose grids 2 mm or less

c) Small-Field Dosimetry

➢ Das *et all*. *Report of AAPM Task Group 155: Megavoltage photon beam dosimetry in small fields and non-equilibrium conditions*. Medical Physics. 2021. Vol 48, Issue 10, Pg. e886-e921.

d) Plan doses are often prescribed to lower isodose levels (80% to 90%)

e) Radiobiological models to compare treatment regimens between SBRT/SRS and conventional dose deliveries

▪ Biologically Equivalent Dose (BED)

▪ Normalized Total Dose (NTD)

▪ These biological indices are useful to compare different fractionation schedules. However, one should be cautioned that the use of linear-quadratic model is only an approximation

9.14   Typical Prescription

a. Brain

✓ SRS: 1500-2200cGy x 1fr

✓ SBRT: 900cGy x 3, 600cGy x 5fr

b. Paraspinal

✓ SRS: 2400cGy x 1

✓ SBRT: 900cGy x 3, 1000cGy x 3, 600cGy x 5

c. Lung SBRT

✓ 750cGy x 8, 1000cGy x 5, 1200cGy x 4, 1800cGy x 3

d. Prostate SBRT

✓ 500cGy x 5 (Post-Brachy), 800-900cGy x 5

9.15   Patient Specific QA

    a)   Commission it well! Spend lots of time

- ✓ Always use an appropriately sized ion chamber on 15-20 plans in high dose and low dose for each energy used as gold standard (distribution about 0)
- ✓ Use two other QA devices to check both are also reading a distribution of 0% error for gamma analysis (including the one you will use regularly) (borrow one if you have to or can!)
- ✓ At the least, QA your QA device monthly (i.e., with a chamber or more sophisticate system—like ArcCheck to check the more efficient portal dosimetry)
- ✓ Think about SRS/SBRT—want a chamber for every plan until you gain confidence? Then QA monthly after you achieve confidence in your commissioning and your machine.

For example, portal dosimetry is very efficient. But the measurements are not ideal according to the AAPM taskgroup report 218 (Perpendicular Field by Field). Also, it is a commissioned system to check another commissioned system. If commissioned wrong, could have passing results for failing plans.

- ✓ Always best to use independent detectors (arrays, film, chambers, etc.) to commission. And follow AAPM TG218 recommendations of True Composite Can check the commissioning of Portal Dosimetry. Then spot check monthly.

- ❖ summary

    a.   Large dose per fraction delivered in fewer fractions (single fraction for SRS)

    b.   Small or no margins (0 to 5 mm)

    c.   Use of Flattening Filter-Free (FFF) beams (Higher Dose Rate)

    d.   Dose calculation using small dose grids 2 mm or less

    e.   Small-Field Dosimetry

    f.   Plan doses are often prescribed to lower isodose levels (80% to 90%)

9.16   Planning Quality Assurance in Treatment Planning

A comprehensive QA program for the whole process implies taking into account many constituents, such as definition of clear aims, appropriate staffing level and qualifications, definition of responsibilities, existence of detailed written procedures, etc. The main issues discussed here are related to QA of the treatment-planning equipment. It must also be ensured that, for individual patients, errors due to wrong data input, incorrect interpretation of results, or inadvertent/undetected failure of equipment will not appear. Therefore, QA procedures related to individual plans must also be devised. For further detail, the reader is referred to the American Association of Physicists in Medicine Report of Task Group 53 the Institute of Physics and Engineering in Medicine Report 81 (IPEM 1999), the ESTRO booklet on QA of treatment planning systems (ESTRO 2004) and the IAEA report TRS 430 (IAEA 2004a).

- ✓ A comprehensive QA programme for the whole process implies taking into account many constituents, such as definition of clear aims, appropriate staffing level and qualifications, definition of responsibilities, existence of detailed written procedures, etc.

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9.17   Acceptance of the treatment planning system

- ✓ Acceptance testing involves testing the function of the hardware and assessment of the system for completeness against the specification. It is unreasonable to expect to carry out a full evaluation of the system at this stage, but sufficient tests should be conducted to identify major deficiencies. It is also wise to test connectivity to other equipment at this stage, but it is unlikely to be possible to test the calculation accuracy unless the manufacturer is able to supply standard beam data for the published test data given in AAPM Report 55 (1995) or Venselaar and Welleweerd (2001). It is similarly important to check the documentation provided

with the system. This must include comprehensive details of the data required and the algorithms used, as well as the standard instructions for use. These instructions must be read carefully, as a treatment planning system can produce unexpected results if not used in the intended fashion (IAEA 2001). The manufacturer must also provide appropriate training particularly of the physicist responsible for the planning data.

Figure 48: Delta4 Phantom containing an array of diodes along the coronal and sagittal axes , used to measure dose distributions in real time

9.18 Set up Treatment

9.18.1 On the linac table

If you have a 6 deg couch, then patient setup Takes as much time as possible, the couch will fine tune any discrepancies.

A. Position the patient within the immobilization device properly.

- ✓ Pay attention to how the patient fits into the vac-lock or the mask

- ✓ When you take a CBCT image, use an appropriate window to also visualize the mask

B. CBCT has a limited field of view.

C. Patient's level of comfort changes from day to day , how they lie on the couch, the arching on their back, the tension in their muscles, etc …

D. Green is the outerbody as taken from CT-sim, clearly there is a difference.

E. Sometimes the spine is visibly arched more.

F. Treatment records show:

➢ Couch rotation of 2.1 and 2.0 deg on two consecutive days.

➢ Couch vertical of 12.2cm and 10.9cm on two consecutive days.

6 deg couch can correct for rotational and translational position errors, however, don't let it do your job.

- ✓ I have seen 5 and 6 degrees of couch rotation on patients while the plans have zero couch rotation!

- ✓ Department established protocols not to allow more than 2 deg corrections (in any angle) using the 6 deg couch.

- ✓ Anything > 2 deg, requires repositioning.

➢ For spine SBRT, the focus is to the spine and the diseased vertebra. As long as the spine curvature is the same, or can be corrected, slight discrepancy in arm positions can be excused.… but don't get too relaxed!! Arm position affects the muscle tension in the back and hence spine curvature.

➢ Craniospinal SRS is easier to setup than SBRT: It actually depends on how well CT-sim staff did their job!

➢ Position the patient within the immobilization device properly.

  a) Pay attention to how the patient fits into the vac-lock or the mask

  b) When you take a CBCT image, use an appropriate window to also visualize the mask

  c) Place the motion management device on the patient exactly as documented by the CT-sim staff

  d) Different location of the RPM cube will yield a different breathing cycle

Not a big deal for phase gating, but makes a large difference for amplitude gating (Breath Hold).

➢ Quick orthogonal pair to get gross alignment.

➢ CBCT scan to align to tumor and tissue.

- ✓ If DIBH is used, the CBCT scan is taken under the same DIBH parameters.

- ✓ If the patient cannot reach the same level of breath hold:

  o Don't take a scan, volume and locations will be different. Can't compare to CT-sim.

  o Coach patient again. If still not capable, don't treat. Re-CT sim and use a diff motion management. Maybe phase gating or chest compression or simply no gating but using ITV.

  a) For prostate and pancreas align with fiducials.

  b) For gated lung, take a floro and verify that the box turns yellow when the tumor is within the gated window.

a) Physics review of the images and approval of setup is followed by clinician final approval.

b) Beam on!

9.18.2 Physics chart review

a) Physics chart review includes offline image reviews.

b) For patients with treatment sessions less than 5 fractions, physics review to occur at an appropriate frequency.

c) The SBRT/SRS physicist reviews all patients under treatments on all machines, hence can catch systematic errors on a certain machine or errors coming out from CT-sim.

d) The physicist's responsibility is to assure proper adherence to protocols and to catch mistakes before they escalate.

9.19   Summary

a) Proper alignment during CT-sim, saves a lot of time during Tx.

b) Use as many images as you need during simulation from motion management to Dx.

c) Know on which images to plan.

d) Setup on the linac will take time. Don't get relxed just because you have a 6 degree of freedom couch.

PRACTICAL STUDY

10 PATIENTS & METHODES

Tableau 5: Technical Card of Center

Chief Doctor	**Pr Lilia naoun**
Institute[	**CLCC , CHU Anaba**
Place (City, Country)	**Anaba, Algeria**
Clinic type	**Public**
Staff	
Number of radiation oncologists in clinic	**14**
Docter	**10**
Number of residents in clinic	**0**
Number of medical physicists and dosimetrists in clinic	**5**
Number of medical technologists in clinic	**6**
Number of therapists Nurse in clinic	**31**
Nurse	**18**
Equipment	
Please detail the machines and their brands	**2 Elekta-infinity , versa HD**
Number of linear accelerators.	**3**
Number of simulation scanners	**1**
Treatment	
Techniques used in your clinic	**3D-CRT** **IMRT** **VMAT** **SBRT** **SRS**
Planning system	**Monaco**
MV Imaging?	**yes**
kV Imaging?	**yes**

10.1   Material and Methods

10.1.1 Material

— Scanner CT : Optima 580 Option Gating 4D

— TPS : Monaco 5.11.03

— Record & Verify   MOSAIQ 2.82

— Linac : Elekta Versa HD

- AlignRT @vision RT Technology

- Delta 4 phantom

- HexaPOD evo

- Patient Setup:

  Lower Vac-Loc provides support and comfort to patient's body

$Imager(III.1)$

Body comfort   Headrest
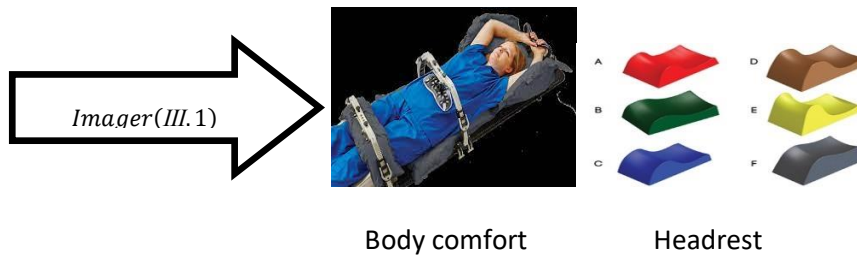
10.1.2 Method

VMAT with 0.2 cm calc grid, 4 arcs, 3 non-coplanar

❖ Introduction :

SRT is a specialized technique in the radiation treatment of small tumors, that it is used only in small tumors whose volume are clear. The designation of SRT differs according to the location of the tumor. If the tumor is at the level of the brain, nerves, and Brain stem, it is called SRS, but if the tumor is at the level of the rest of the body, it is called SBRT.

SRT is used in small tumors that are difficult to treat surgically, and with its presence near sensitive organs and cells, as well as it is used as an alternative to chemotherapy.

By relying on 3 criteria in accepting the treatment plan, which are CI (less than 2%), Coverage (%) for GTV and PTV , and OAR. The results are acceptable, and according to the percentage of OAR, we seek to protect giving the lowest possible dose of OARs to maintain them, and that is according to the medical publication for calculating doses Timmermen . The dose is chosen according to the radiation sensitivity of the organ, as there are organs that are calculated $Dose_{max}$ and other organs are calculated $Dose_{mean}$ according to Timmerman SBRT dose constraints

Tableau 6: Comparison of typical characteristics of 3D/IMRT radiotherapy and SRT

Characteristic	Normofractionated	SRT
Dose / Fraction	**1.8 – 2.5 Gy**	**6 – 30 Gy**
Fractions	**10 – 35**	**1-8**
Target definition	**GTV /CTV / PTV (gross disease + clinical extension): tumor may not have a sharp boundary.**	**GTV / CTV / ITV/ PTV (well-defined tumors: GTV=CTV)**
Margin	**Centimeters**	**Millimeters**
Physics / dosimetry monitoring	**Indirect**	**Direct**
Required setup accuracy	**TG142**	**TG142**
Primary imaging modalities used for treatment planning	**CT**	**Multi-modality: CT ; IRM ; PET/CT**
Redundancy in geometric verification	**No**	**Yes**
Maintenance of high spatial targeting accuracy for the entire treatment	**Moderately enforced (moderate patient position control and monitoring)**	**Strictly enforced (sufficient immobilization and high frequency position monitoring through integrated image guidance)**
Need for respiratory motion management	**Moderate – must be at least considered**	**Highest**
Staff training	**Highest**	**Highest + special SBRT training**
Technology implementation	**Highest**	**Highest**
Radiobiological understanding	**Moderately well understood**	**Poorly understood**
Interaction with systemic Therapies	**Yes**	**Yes**

10.2   Pathological Conditions

1 – A230157	
Age	68
Sex	Man
Radiotherapy oncology Medical Physicist	Dr Bouakaze Lila Bacha Billel
Exame clinic	Normal
Paraclinic	PET; IRM ; CT
Localisation of tumer	Femur R
Volum of tumor	12CC
RCP	This's the patient who presented with prostate ADK in 2015 initially classified as pt3an1M0R1 Currently M+ OS(femoral diaphysis steriotaxcy) if the dose passes Quantitative dosemeter data has been requested
Histologie	Diabetic Type 2 Prostatectomy in March 2015 PSA 0.55ng
Chirurgie	Yes
Chimiothérapie	Yes
Radiotherapy	Palliative

10.2.1 CT SCAN

10.2.1.1   Scan limits:

- Sup border: pelvis

- Inf border: knee

Figure 49: Scan limits

Document sup/inf position where clearance is confirmed using Hexapod measurement Tool

10.2.1.2   Scan Orientation (CT1) :

− Feet First Supine

Figure 50: Scan Orientation (CT1)

10.2.1.3   Slice spacing:

− standard (1,25 mm)

10.2.1.4   Number of image CT :

− 465 CT

Figure 51: Number of Image CT and Slice spacing

− CT Reference: 7 cm below SSN, identified with BBs

− Tattoos: leveling tattoos midline, midplane

− Send CT to Monaco VIA DICOM

Figure 52: DICOM

10.2.2 Contouring

10.2.2.1   Target Definition :

PTV=GTV + 0.5cm

10.2.2.2   OARs Contouring:

Body , Fumer (R) , Fumer (L) , blader
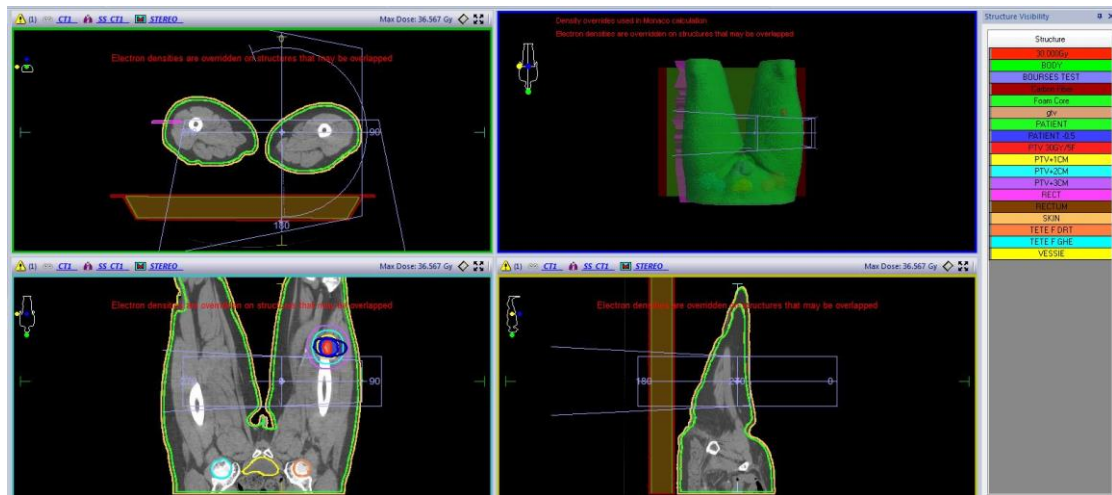
Figure 53: Contouring OF Target Definition and OARs

10.2.3 Dosimetry

10.2.3.1 Technique :

Stereotactic Body Radiation Therapy (SBRT)

10.2.3.2 Calculation :

Ray tracing (Monte Carlo at discretion of Tretment planner)

10.2.3.3 Prescription :

30 Gy / 5 Fraction Treatment

10.2.3.4 Isocenter Treatment:

Isocenter must be no more than≤ 5 cm from the center of any GTV , Tolerance doses for w Rx tolerance doses:

- ✓ GTV: D100% ≥ Rx dose
- ✓ PTV: Dmax = 125% Rx dose
- ✓ PTV: D100% > 75% of Rx dose hich PTV coverage must be compromised

10.2.3.5 Planning Goals :

- ✓ 50% of prescription dose to be within 2 cm of PTV
- ✓ 30% of prescription dose to be within 3 cm of PTV
- ✓ $HI_{ICRU\ 83}$ = (D2%–D98%)/D50% =(35,75-30) /33,768 = 0.17

10.2.3.6 OAR tolerance doses:

As per @Timmerman SBRT dose constraints: Sem Rad Onc, v18(4), 2008, p.215-222

10.2.4 DVH (Dose Volume Histogramme)
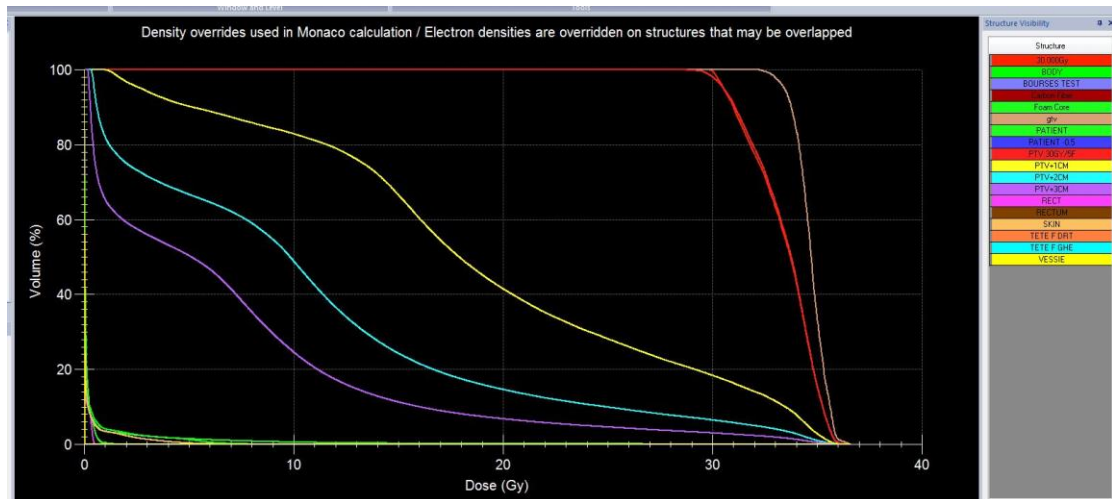
Figure 54: DVH

10.2.5 Radiobiology Clinic

$$BED = nd \left[1 + \frac{d}{\propto/\beta}\right] = 5 \times 30 \left[1 + \frac{30}{10}\right] = 60\text{Gy}$$

$$\text{EQD}_2 = \frac{BED}{1 + \frac{2}{\propto/\beta}} = \frac{60}{1 + \frac{2}{10}} = 50\text{Gy}$$

10.2.6 QA for the 6d Table

We monitor the quality of table movement in all directions

Figure 55: QA for the 6d table

10.2.6.1   Position Table

We place the patient on the treatment table and match the laser to the anatomical reference tattoo of the tumor

Figure 56: Position Table

Visionrt Technology: We chose the Visiort technique in this case because the organ (thigh) to be treated is not fixed

Figure 57: Visionrt Technology

10.2.7 Set up Treatment

Figure 58: Visionrt Technology

10.2.7.1 Control Sut up Treatment Patient by CBCT

Correcting the patient's position it's (x,y,z) =3mm max and 2° max

Figure 59: CBCT

➢ Note:

On the second day of treatment 2 fraction , we noticed through CBCT a decrease in tumor size

10.3   Results and discussion

In this pathological case, for tumor at the level of femur R its size is 12 mm, where we set the medical protocol (Prescription) it 30 Gy in 5 days(Fraction Treatment) and treated it with SBRT technique, and we got the following results:
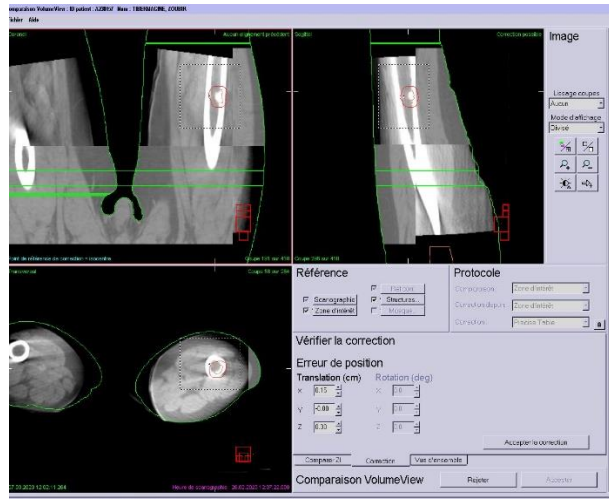
	PTVs Target	Dose(Gy)	Target Volume(cc)	Isodose 100 % volume(cc)	Conformity Index	HI	Coverage (%)	Target D100(Gy)	Target D90(G
	GTV	30	2.023	/	/	/	100	30	33.75
1	PTV(SBRT)	30	10.770	10.976	0.93	0,17	98	28.096	31.07

a) Into CI, we recorded 0.93<2% and according to Coverage into GTV =100% and PTV=98%

b) For OARs we have recorded low doses for all OARs that are compatible with Timmerman Dose constraints SBRT

Serial tissue	Volume (cm3)	Max Point Dose (Gy)	Avoidance Endpoint if exceed the permissible dose
Skin	2825.704	9.004	Ulceration
Head Fumeral R	119.436	0.026	
Head Fumeral L	119.730	0.014	

c) Therefor (a and b) we conclude that the treatment plan is acceptable and compatible with the approved medical publication

d) The delivery Treatment

The delivery dose time: 3.30-3.40 min

Dose rate and modulation intensity: 400MU/min

e) Control Pation

Control Clinic after 1month and PET scanne after 3 month

2 – A210051	
Age	53
Sex	Women
Radiotherapy oncology	Dr Menasria Meriem
Exame clinic	Normal
Paraclinic	TDM (thoracique); PET/CT ; Biopsie ; MRI
Localisation of tumer	Lung L

Volum of tumur	3.166 CM3
RCP	M+ lung L
Histologie	Breast Cancer
Chirurgie	No
Chimiothérapie	No
Radiotherapy	Curative

❖ Preface :

In this work we condicted a comparative study between SBRT-VMAT, IMRT and 3DCRT through which we aim to determine the advantages of SRT in the treatment of small tumors and the preservation of OAR

1. CT SCAN

1.2 Scan limits:

Sup border: shoulders

Inf border: Thoracic Diaphragem

Document sup/inf position where clearance is confirmed using Hexapod measurement Tool

1.3 Scan Orientation (CT1) : Head First Supine

1.4 Slice spacing: standard (2 mm)

1.5 Number of image CT : 465 CT

1.6 CT Reference: 7 cm below SSN, identified with BBs

1.7 Tattoos: leveling tattoos midline, midplane

Send CT to Monaco VIA DICOM

2. Contouring

2.1 Target Definition :

GTVs (max size of 5 cm in any direction)

ITVs: determined with MIP (max sup-inf motion of 1.0 cm in any direction)

PTVs: ITV + 0.5 cm Entire esophagus (from cricoid superiorly to gastro-esoph. junction inferiorly
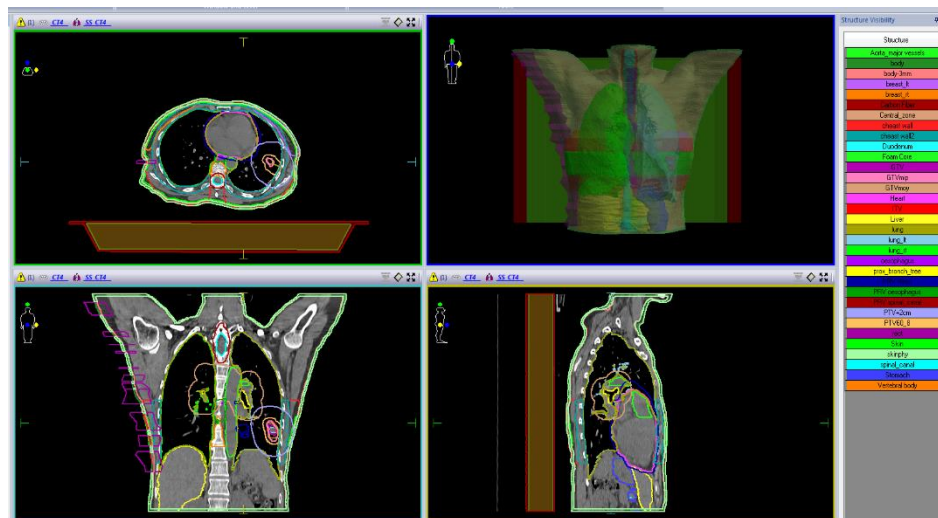
2.2 OARs Contouring:

Figure 60: Contouring Of Target Definition and OARs

3. **Dosimetry**

   3.1 Technique: Stereotactic Body Radiation Therapy (SBRT)

   3.2 Calculation: Ray tracing (Monte Carlo at Discretion of Tretment Planner)

   3.3 Prescription : 60 Gy / 8 Fraction Treatment (SBRT)

   3.4 Isocenter Treatment :

   Isocenter must be no more than≤ 5 cm from the center of any GTV , Tolerance doses for w Rx tolerance doses:

   ITV: Dmax<140% of prescription dose

   PTV: Volume prescription Dose > 95% of Rx dose hich PTV coverage must be compromised

   PTV: D98% > 95% of prescription dose of Rx dose hich PTV coverage must be compromised

   PTV: D99% > 90% of prescription dose of Rx dose hich PTV coverage must be compromised

   3.5 Planning Goals ：

   %50of prescription dose to be within 2 cm of PTV

   HI_{ICRU38}(3DCRT) = (D2%–D98%)/D50% =(65.521-54.625) /60.674 = 0.17   ICRU 83

   HI_{ICRU38}(IMRT) = (D2%–D98%)/D50% =(67.565-58.888) /62.232 =0.13ICRU 83

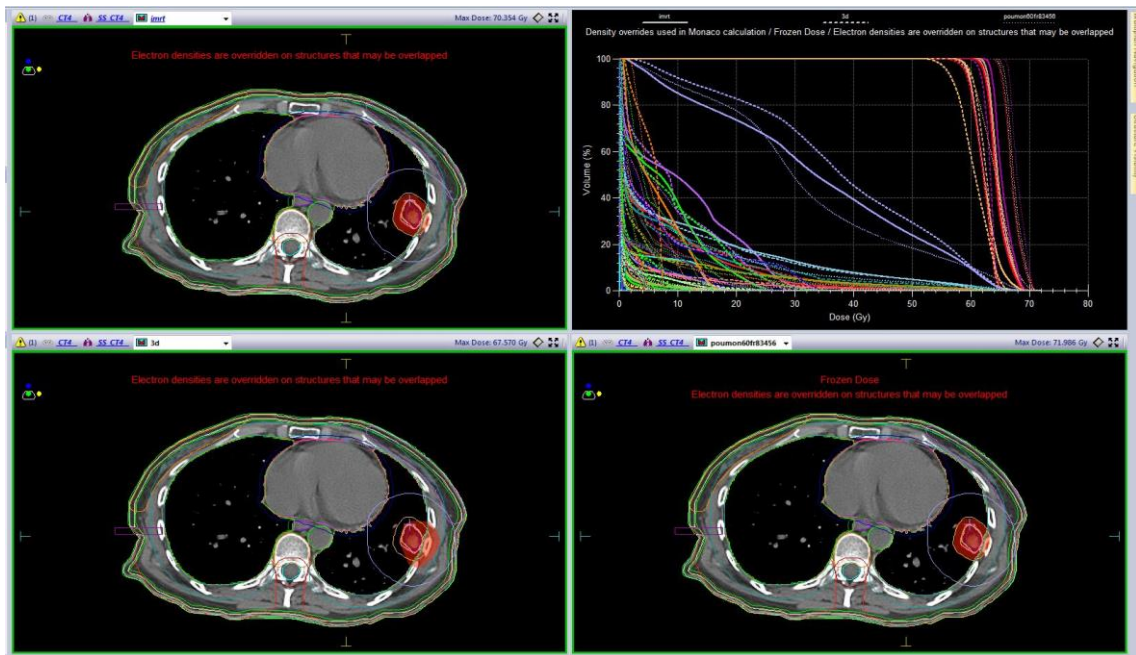 HI_{ICRU38}(SBRT) = (D2%–D98%)/D50% =(69.59-58.733) /64.232 = 0.16ICRU 83
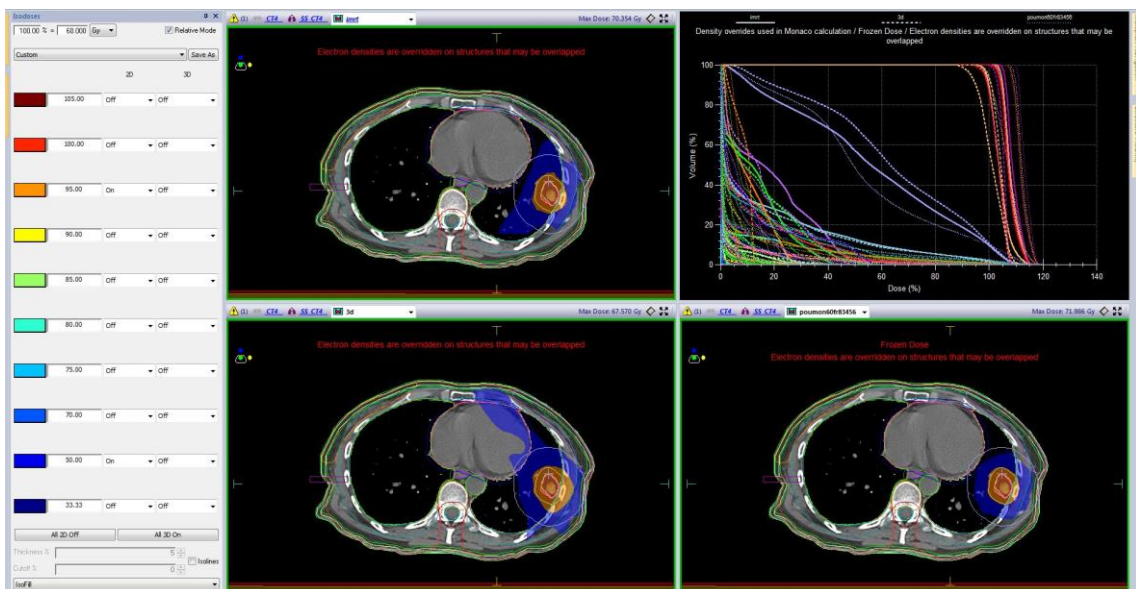
Figure 61 :Covrege of GTV

Figure 62 : Weak Dos

3.6 OAR tolerance doses:

As per @Timmerman SBRT dose constraints: Sem Rad Onc, v18(4), 2008, p.215-222

4. DVH (Dos Volume Histogramme) :
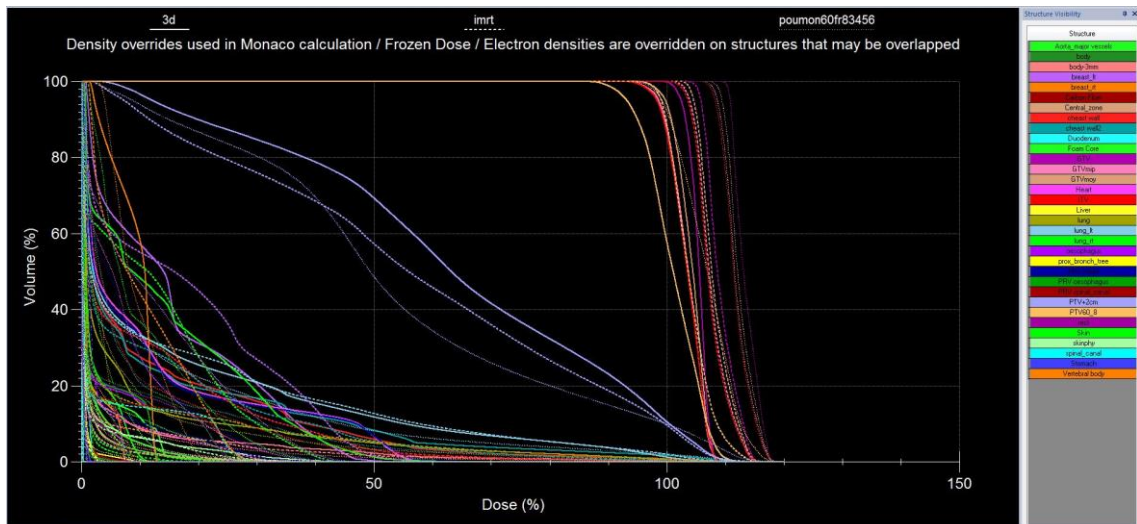
Figure 63 :DVH

5. Radiobiology clinic

$$BED = nd \left[1 + \frac{d}{\propto/\beta}\right] = 8 \times 60 \left[1 + \frac{60}{10}\right] = 3360 \text{Gy}$$

$$EQD_2 = \frac{BED}{1 + \frac{2}{\propto/\beta}} = \frac{3360}{1 + \frac{2}{10}} = 2800 \text{Gy}$$

6. Set up Treatment : On the linac table

Control sut up treatment patient by CBCT

Correcting the patient's position it's (x,y,z) =3mm max and 2° max
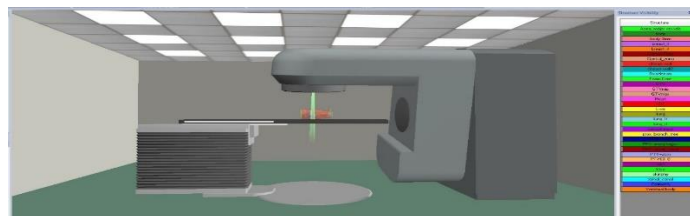
Figure 64 : Set up Treatment

❖ Results and discussion

In this pathological case, for tumor at the level of lung L its size is 12 mm, where we set the medical protocol (Prescription) it 30 Gy in 5 days(Fraction Treatment)   , we're simulated treatment dose calculation with 3 Techniques 3DCRT,IMRT and SBRT recorded the following This results:

PTVs Target	Dose(Gy)	Target Volume(cc)	Isodose 100 % volume(cc)	Conformity Index	HI	Coverage (%)	Target D100(Gy)	Target D90(Gy)
GTV(3DCRT)	60	3.203	/	/	/	99.78	59.399	61.940

PTV(3DCRT)	60	27.513	27.461	1.0018	0 .17	58.07	51.556	57.00
GTV(IMRT)	60	3.166	/	/	/	100	61.677	63.768
PTV(IMRT)	60	27.545	25.240	0.88	0.13	89.51	55.402	59.959
GTV(SBRT)	60	3.166	/	/	/	100	65.564	66.627
PTV(SBRT)	60	27.545	25.923	0.91	0,16	92.88	53.929	60.422

Figure 65 :Planning Goals

a) Into CI, we recorded CI_{3DCRT}=1.0018 ;CI_{IMRT}=0.88 and CI_{SBRT}=0.91<2% , and into Coverage we scored the best results in SBRT GTV =100% and PTV=92.88%

b) For OAR_s We recorded a few doses in three techniques 3DCRT,IMRT and SBRT Except that, but For spinal canal we recorded Dos $_{max}$ =6.502 Gy
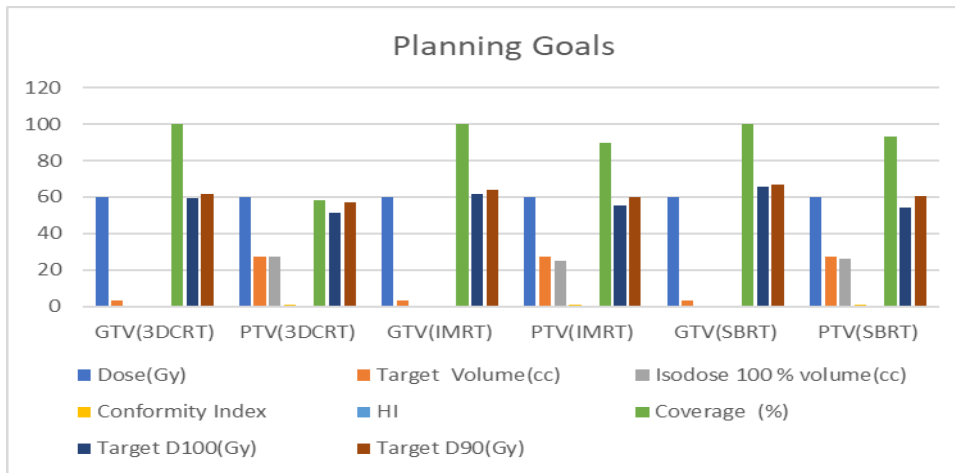
serial tissue	Volume (cm3)	Max Point Dose (Gy) / Dos moy	Avoidance Endpoint if exceed the permissible dose
SkinPhy (3DCRT)	2825.704	38.219	Ulceration
SkinPhy (IMRT)	1242.201	23.857	Ulceration
SkinPhy (SBRT)	1242.201	23.551	Ulceration
PRV spinal canal (3DCRT)	228.243	6.111	Myelitis
PRV spinal canal (IMRT)	226.667	18.769	Myelitis
PRV spinal canal (SBRT)	226.667	6.502	Myelitis
Oesophagus (3DCRT)	33.300	7.925	Stenosis/fistula
Oesophagus (IMRT)	33.359	1.499	Stenosis/Fistula
PRV oesophagus (SBRT)	91.896	16.984	Stenosis/Fistula
PRV Heart (3DCRT)	784.767	43.247	Pericarditis
PRV Heart (IMRT)	785.862	31.017	Pericarditis
PRV Heart (SBRT)	785.862	34.460	Pericarditis
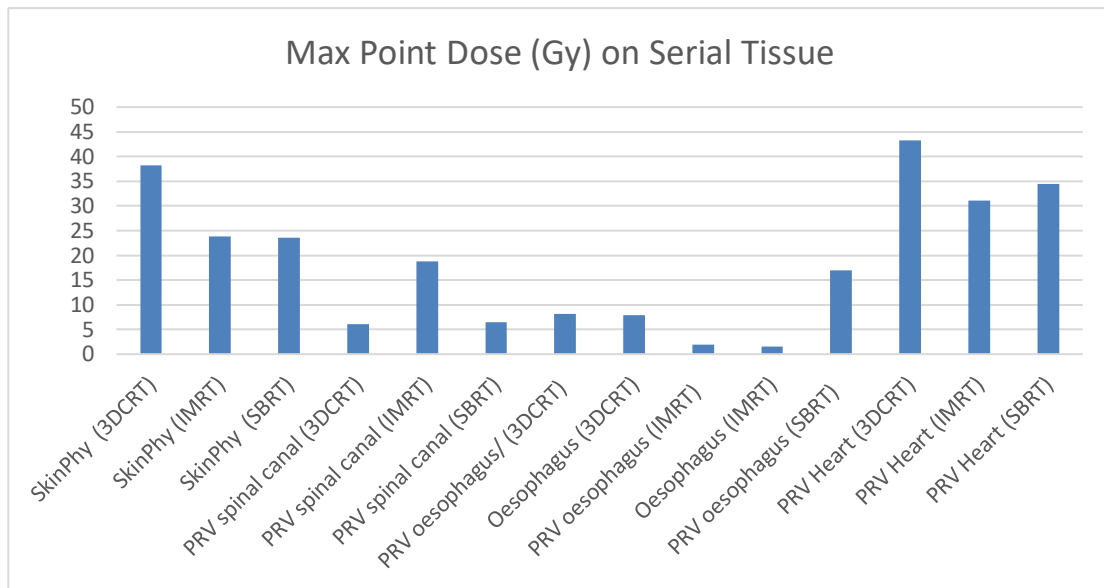
Figure 65: Dose Max Serial Tissue

Parallel Tissue	Critical Volume	Critical Volume Dose Max (Gy)	Avoidance Endpoint if exceed the permissible dose
Lung L (3DCRT)	1089.137	66.152	Pneumonitis
Lung R (3DCRT)	1393.947	7.458	Pneumanitis
Lung (3DCRT)	2574.682	66.473	Pneumanitis
Lung L (IMRT)	1086.360	70.128	Pneumonitis
Lung R (IMRT)	1397.540	12.234	Pneumonitis
Lung (IMRT)	2579.084	68.508	Pneumonitis
Lung L (SBRT)	1086.360	71.986	Pneumonitis
Lung R (SBRT)	1397.540	13.421	Pneumonitis
Lung (SBRT)	2579.084	70.061	Pneumonitis
Cheast wall2 (3DCRT)	701.093	67.570	Necrosis
Cheast wall2 (IMRT)	701.954	65.719	Necrosis
Cheast wall2 (SBRT)	701.954	68.714	Necrosis
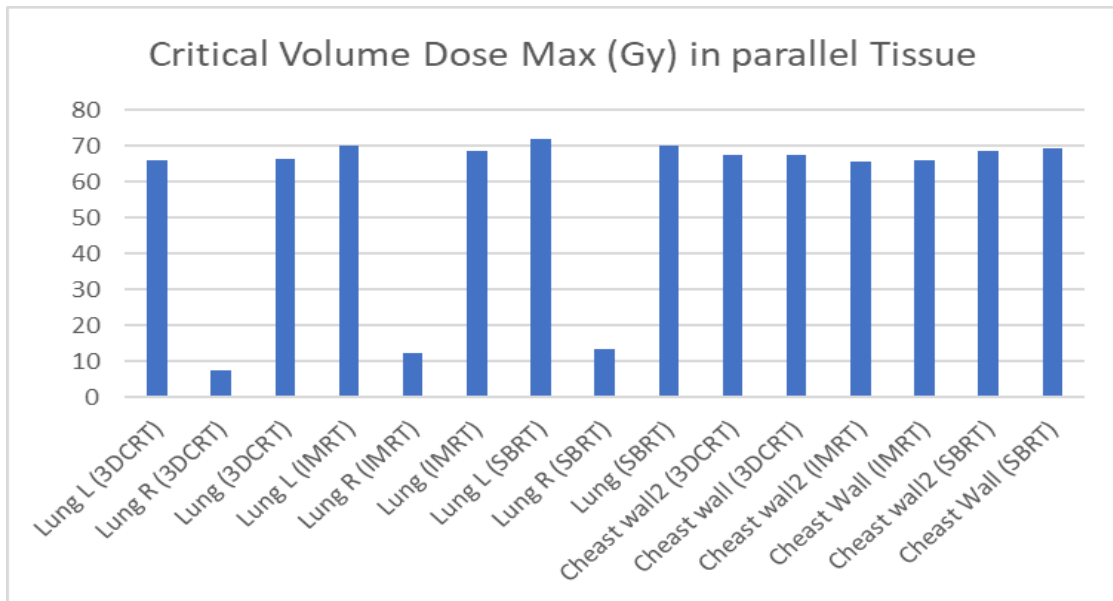
Figure 60: Dose Max Parallel Tissue

c) Therefor (a and b) we conclude that the technique SBRT, is more compatible with this case in accordance with the medical publication and internationally approved protocols

d) The delivery Treatment

The delivery dose time: 3.30-3.40 min

Dose rate and modulation intensity: 400MU/min

7. Control Pation

Control Clinic after 1month and PET scanne after 3 month

3- A221500	
Age	**46**
Sex	**Women**
Radiotherapy oncology	**Dr Teyar Imane**
Exame clinic	**Normal**
Paraclinic	**TDM ; Scintigraphy bone ; MRI ; PA**
Localisation of tumer	**Vertable**
Volum of tumur	**6.112 CM3**
RCP	**M+ Bone**
Histologie	**Breaste Cancer**
Chirurgie	**Yes**
Chimiothérapie	**Yes**
Radiotherapy	**Curative**

1. CT SCAN

1.1 Scan Orientation (CT1) : Head First Supine

1.2 Slice spacing: standard (1,25 mm)

1.3 Number of image CT : 313 CT

1.4 CT Reference: 7 cm below SSN, identified with BBs

1.5 Tattoos: leveling tattoos midline, midplane

 Send CT to Monaco VIA DICOM

2. Contouring

2.1 Target Definition :

GTV: MR-guided gross tumour volume

CTV: GTV + margin to account for micro-and macroscopic disease

30 CTV 5 , CTV PHY

PTV: 2mm uniform expansion around CTV

PTV30/5 , ptv 3cm , PTV phy , PTV phy 1 , PTV +1cm , PTV + 2cm

2.2 OARs Contouring:
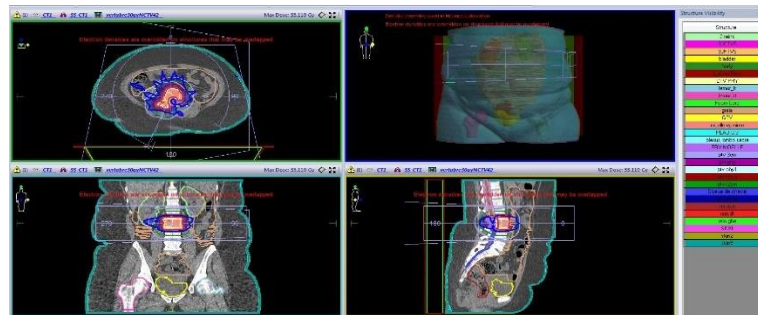
Figure 67 : Contouring GTV

3. Dosimetry

3.1 Technique : Stereotactic Body Radiation Therapy (SBRT)

3.2 Calculation: Ray tracing (Monte Carlo at discretion of Tretment planner)

3.3 Prescription : 24 Gy / 3 Fraction Treatment

3.4 Isocenter Treatment:

Isocenter must be no more than≤ 5 cm from the center of any GTV , Tolerance doses for w Rx tolerance doses:

GTV: D100% ≥ Rx dose

PTV: Dmax = 125% Rx dose

PTV: D100% > 75% of Rx dose hich PTV coverage must be compromised

3.5 Planning Goals :

50 %of prescription dose to be within 2 cm of PTV

HI_{ICRU38} = (D2%–D98%)/D50% =(32.137-12.996) /27.341 = ICRU 83
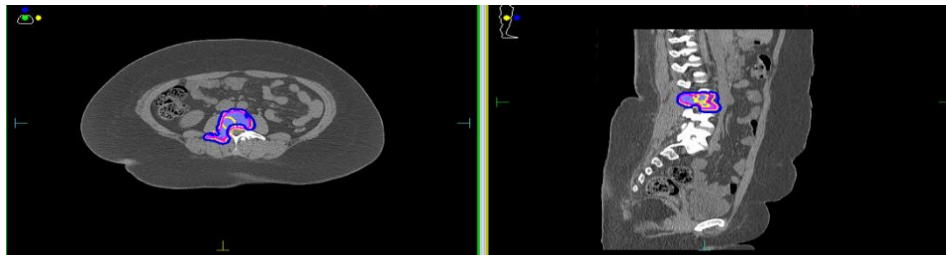
Figure 67 : Coverage

3.6 OAR tolerance doses:

As per @Timmerman SBRT dose constraints: Sem Rad Onc, v18(4), 2008, p.215-222

4. DVH (Dos Volume Histogramme) :
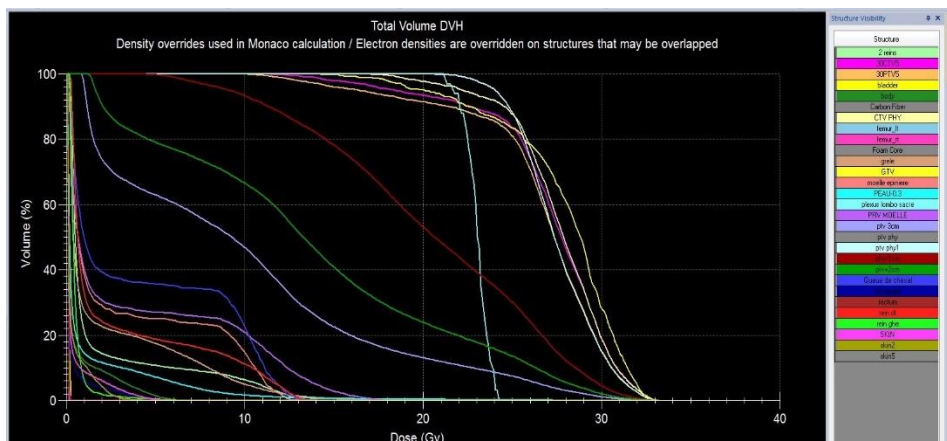
Figure 68 : DVH

5. Radiobiology clinic

$$BED = nd \left[1 + \frac{d}{\propto/\beta} \right] = 3 \times 24 \left[1 + \frac{24}{10} \right] = 244.8 \text{Gy}$$

$EQD_2 = \frac{BED}{1 + \frac{2}{\propto/\beta}} = \frac{244.8}{1 + \frac{2}{10}} = 204 \text{Gy}$

6. Set up Treatment : On the linac table

Control sut up treatment patient by CBCT

Correcting the patient's position it's (x,y,z) =3mm max and 2° max
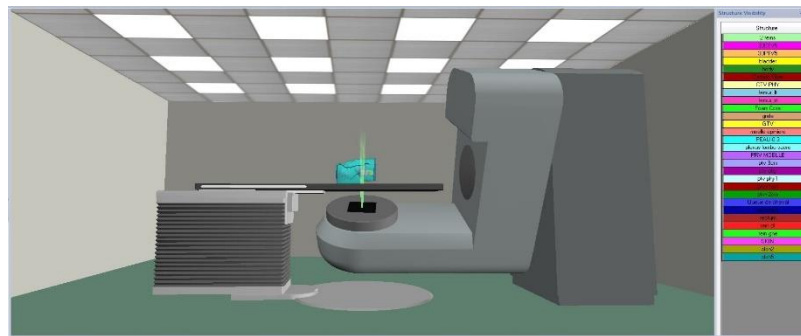
Figure 69 : Set up Treatment

❖ **Results and discussion**

In this pathological case, for tumor at the level of Vertable its size is 6.112 cm3, where we set the medical protocol (Prescription) it 24Gy in 3days(Fraction Treatment) and treated it with SBRT technique, and we got the following results:

| PTVs Target	Dose (Gy)	Target Volume(cc)	Isodose 100 % volume(cc)	Conformity Index	HI	Coverage (%)	Target D100(Gy)	Target D90(Gy)
GTV	24	6.112	/	/	/	86.65	14.251	22.570
PTV(stero)	24	56.472	69,843	0.15	0,70	85.53	9.746	21.428

a) Into CI, we recorded 0.15<2% and according to Coverage into GTV =86.65% and PTV=85.53%

b) For OARs we have recorded low doses for all OARs that are compatible with Timmerman Dose constraints SBRT

serial tissue	Volume (cm3)	Max Point Dose (Gy)	Avoidance Endpoint if exceed the permissible dose
Skinphy	2825.704	9.004	Ulceration
PRV spinal canal	49.024	18.251	Myelitis
Plexus lombo sacre	0.528	24.158	/
Bladder wall	128.752	0.215	Cystitis/fistula
Grele	2964.360	25.951	Enteritis/Obstruction
Rectum	79.440	0.018	Proctitis/Fistula

Parallel Tissue	Critical Volume	Critical Volume Dose Max (Gy)	Avoidance Endpoint if exceed the permissible dose
Renal 2	348.296	16.309	Basic renal function
Ponytail	12.976	13.662	/
Femoral heads L	127.424	0.078	Necrosis
Femoral heads R	132.168	0.082	Necrosis

c) Therefor (a and b) we conclude that the treatment plan is acceptable and compatible with the approved medical publication

d) The delivery Treatment

The delivery dose time: 3.30-3.40 min

Dose rate and modulation intensity: 400MU/min

a) Control Pation

Control Clinic after 1month and PET scanne after 3 month

4- A221353	
Age	63
Sex	Man
Radiotherapy oncology	Pr Mansori Soumeya
Exame clinic	Can'nt wealk
Paraclinic	TDM ; MRI
Localisation of tumer	Brain
Volum of tumur	1.639 CM3
Histologie	No smell Lung Canser
Chirurgie	No
Chimiothérapie	Yes
Radiotherapy	Curative

❖ Preface :

In this work we condicted a comparative study between SRS-VMAT, IMRT and 3DCRT through which we aim to determine the advantages of SRT in the treatment of small tumors and the preservation of OAR .

1. CT SCAN

1.1 Scan Orientation (CT1) : Head First Supine

1.2 Slice spacing: standard (1,25 mm)

1.3 Number of image CT : 325 CT

1.4 CT Reference: 7 cm below SSN, identified with BBs

1.5 Tattoos: leveling tattoos midline, midplane

Send CT to Monaco VIA DICOM

2. Contouring

2.1 Target Definition : PTV=GTV+3mm

2.2 OARs Contouring:

Figure 69 : Contouring of Target Definition and OARs

3. Dosimetry

3.1 Technique: Stereotactic Radiosurgery (SRS)

3.2 Calculation: Ray tracing (Monte Carlo at discretion of Treatment planner)

3.3 Prescription: 30 Gy / 5 Fraction Treatment (SRS)

3.4 Isocenter Treatment:

Isocenter must be no more than≤ 5 cm from the center of any GTV ,
Tolerance doses for w Rx tolerance doses:

GTV: D100% ≥ Rx dose

PTV: Dmax = 125% Rx dose

PTV: D100% > 75% of Rx dose hich PTV coverage must be compromised

3.5 Planning Goals :

50 %of prescription dose to be within 2 cm of PTV

30 % of prescription dose to be within 1 cm of PTV

HI_{ICRU38}(3DCRT) = (D2%–D98%)/D50% = (33.583-29.729) /32.079 =0.12 ICRU 83

HI_{ICRU38}(IMRT) = (D2%–D98%)/D50% = (34.1-28.058) /32.513 =0.18 ICRU 83

HI_{ICRU38}(SRS) = (D2%–D98%)/D50% = (36.026-28.267) /33.76 =0.22 ICRU 83

Figure 70: Planning Goals

3.4.1   OAR tolerance doses

As per @Timmerman SBRT dose constraints: Sem Rad Onc, v18(4), 2008, p.215-222

Figure 71: Contouring of Target Definition and OAR

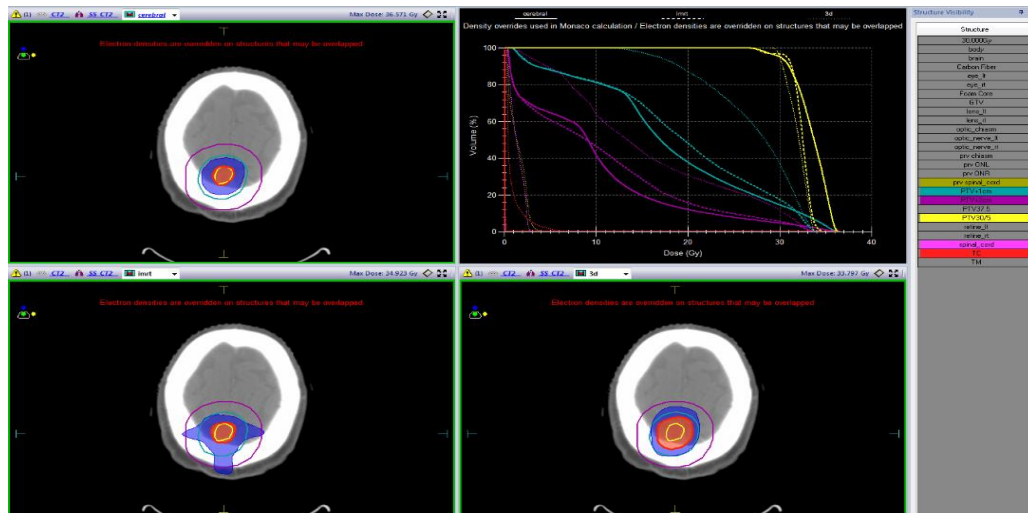## 4.   DVH (Dose volume histogramme)

Figure 72: DVH and Coverage in Planning Goals into (3DCRT ; IMRT and SRS)

5. **Radiobiology clinic**

$$BED = nd \left[1 + \frac{d}{\propto/\beta}\right] = 5 \times 30 \left[1 + \frac{30}{10}\right] = 600 Gy$$

$$EQD_2 = \frac{BED}{1 + \frac{2}{\propto/\beta}} = \frac{600}{1 + \frac{2}{10}} = 500 Gy$$

6. **Set up Treatment :** On the linac table

   Control sut up treatment patient by CBCT

   Correcting the patient's position it's (x,y,z) =3mm max and 2° max
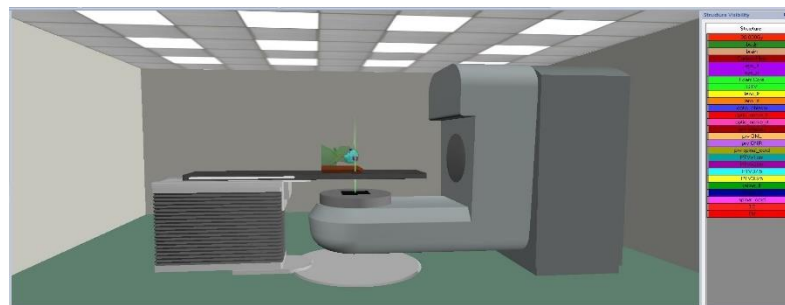

Figure 73: Set up Treatment On the linac table

6.1   Results and discussion

In this pathological case, for tumor at the level of cerberal its size is 1.639 cm3 , where we set the medical protocol (Prescription) it 30 Gy in 5 days(Fraction Treatment) , we're simulated treatment dose calculation with 3 Techniques 3DCRT,IMRT and SBRT recorded the following This results:

Tableau 7:

PTVs Target	Dose(Gy)	Target Volume(cc)	Isodose 100 % volume(cc)	Conformity Index	HI	Coverage (%)	Target D100(Gy)	Target D90(Gy)
GTV(3DCRT)	30	1.639				100	30.064	30.761
PTV(3DCRT)	30	5.982	16.416	0.36	0 .12	94.98	32.652	30.310
GTV(IMRT)	30	1.639				100	31.556	32.212
PTV(IMRT)	30	5.982	7.771	0.69	0.19	96.71	26.533	31.304
GTV(SRS)	30	1.639	/			100	33.495	34.643
PTV(SRS)	30	5.982	6.490	0.82	0.22	95.18	26.6332	31.022

a) Into CI, we recorded $CI_{SRS}=0.82$; $CI_{IMRT}=0.69$ and $CI_{3DCRT}=0.36<2\%$, and into Coverage we recorded into GTV is 100% in all the techniques SRS,IMRT and 3DCRT , And for PTV we recorded $PTV_{SRS}=95.18\%$ It is a value that converges well with the results of other techniques $PTV_{3DCRT}=94.98\%$, $PTV_{IMRT}=96.71\%$

b) For OAR_s We recorded into Dos_{OAR}, we recorded in this case very weak doses, for comparison between the results of the three techniques SRS,IMRT and 3SCRT , we find that the Dos_{OAR} in SRS technique are less Dos Whithin IMRT and 3D technique , except for Brain, but its dose acceptable.

Tableau 8:

Serial Tissue	Volume (cm3)	Max Point Dose (Gy)	Avoidance Endpoint if exceed the permissible dose
Spinal Canal (3DCRT)	49.024	4.176	Myelitis
Spinal Canal (IMRT)	49.024	0.066	Myelitis
Spinal Canal (SRS)	49.024	0.041	Myelitis
Chiasm (3DCRT)	0.528	0.329	Neuritis
Chiasm (IMRT)	0.528	0.132	Neuritis
Chiasm (SRS)	0.528	0.121	Neuritis
BrainStem (3DCRT)	24.40	6.585	Cranial Neuropathy
BrainStem (IMRT)	24.40	0.146	Cranial Neuropathy
BrainStem (SRS)	24.40	0.149	Cranial Neuropathy
OpticNerve_R (3DCRT)	1.143	0.221	Neuritis
OpticNerve_R (IMRT)	1.143	0.115	Neuritis
OpticNerve_R (SRS)	1.143	0.092	Neuritis
OpticNerve_L (3DCRT)	0.999	0.227	Neuritis
OpticNerve_L (IMRT)	0.999	0.106	Neuritis

|			
OpticNerve_L (SRS)	0.999	0.092	Neuritis
Brain (3DCRT)	1269.196	33.797	/
Brain (IMRT)	1269.196	34.923	/
Brain (SRS)	1269.196	36.571	/
Lens_R (3DCRT)	0.20	0.175	Neuritis
Lens_R (IMRT)	0.20	0.095	Neuritis
Lens_R (SRS)	0.20	0.064	Neuritis
Lens_L (3DCRT)	0.20	0.08	Neuritis
Lens_L (IMRT)	0.20	0.069	Neuritis
Lens_L (SRS)	0.20	0.065	Neuritis
Eye_L (3DCRT)	8.389	0.118	Neuritis
Eye_L (IMRT)	8.389	0.110	Neuritis
Eye_L (SRS)	8.389	0.107	Neuritis
Eye_R (3DRT)	7.922	0.213	Neuritis
Eye_R (IMRT)	7.922	0.138	Neuritis
Eye_R (SRS)	7.922	0.091	Neuritis
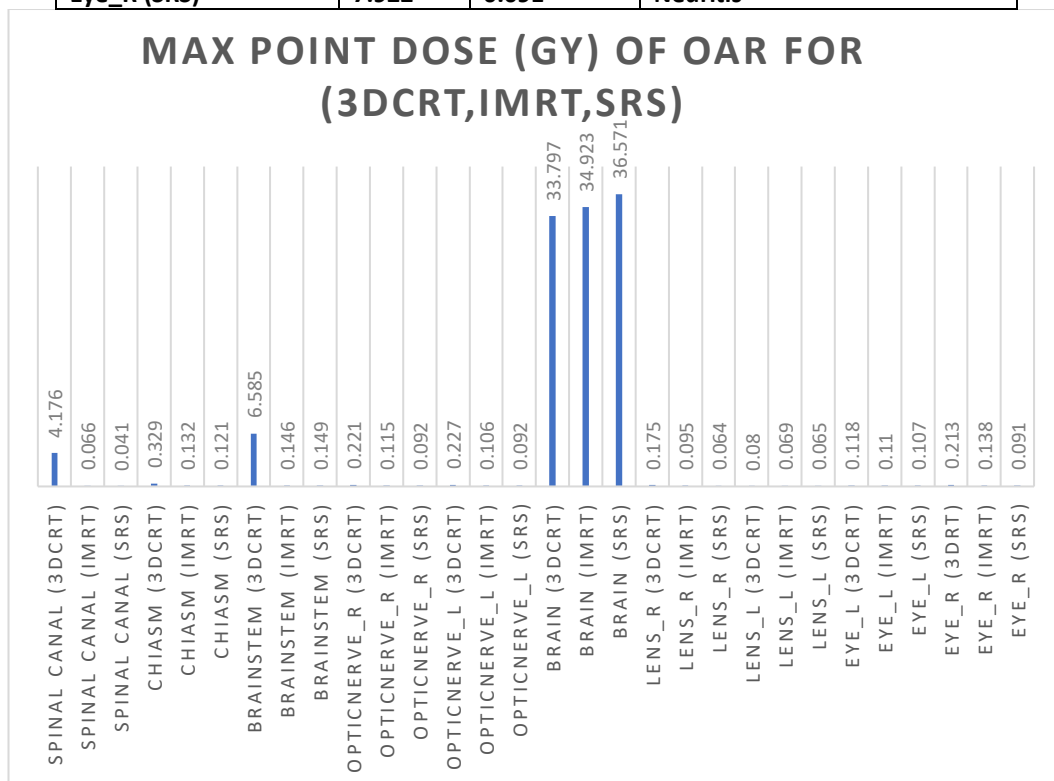
Figure 74: Dose Max of OAR

c) Therefor (a and b) we conclude that the technique SRS, is more compatible with this case in accordance with the medical publication and internationally approved protocols

d) The delivery Treatment

The delivery dose time: 3.30-3.40 min

Dose rate and modulation intensity: 400MU/min

e) Control Patient

Control Clinic after 1month and PET scanner after 3 months

6.2   QA For (TPS)

6.2.1   The Delta4 Phantom[23]

The Delta4 Phantom+ system offers the most accurate and efficient verification of your IMRT, VMAT, Halcyon, Radixact, and TomoTherapy plans.

It is the ONLY system that measures the dose distribution in the isocentric region and not simply in one single flat or wrapped plane.

Figure 61: The Delta4 Phantom

6.2.2   Gamma Index

It's report for single-institution experience of gamma evaluations with 2%/2 mm for stereotactic ablative radiotherapy (SABR) delivered with volumetric modulated arc therapy (VMAT) technique[24]
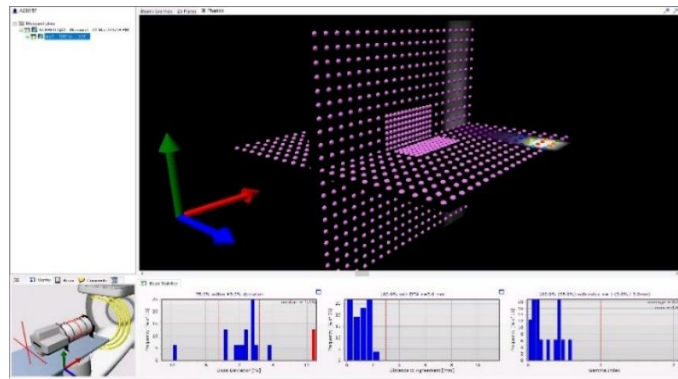
Figure 62: The system of Gamma Index QA (TPS)

❖ Conclusion

1. SRT is effective treatment for small tumer and Functional Medical Conditions

2. SRT is treatment technique radiotherapy to be Preservation OARs

3. We can use SRT as an alternative to chemotherapy and Surgery

4. As a comparison Between Radiotherapy Techniques , SRT technique characterized a short treatment Fraction

5. Dosimetry SRT depends on coverage of GTV,PTV and Conformity Index for PTV ; and mess Dos of OARs

❖ **Abstract:**

   Stereotactic Radiotherapy SRT is an effective technique in the treatment of small tumors ≤ 5 cm^3, the nervous system and the brain, as it enables us to protect the OAR, as well as the number of treatment sessions is small compared to other Radiotherapy techniques IMRT and 3DCRT, and it can also be used instead of surgery and chemotherapy

➢ **Key Words:**

   SRT ,OAR,IMRT,3DCRT

❖ **Résumé:**

   La stéréotaxique radiothérapie SRT est une technique efficace dans le traitement des petites tumeurs ≤ 5 cm^3, du système nerveux et du cerveau, car elle permet de protéger l'OAR, ainsi que le nombre de séances de traitement est faible par rapport aux autres techniques de radiothérapie IMRT et 3DCRT , et il peut également être utilisé à la place de la chirurgie et de la chimiothérapie

➢ **Mots Clés:**

   SRT ,OAR,IMRT,3DCRT

❖ **ملخص**

العلاج الاشعاعي تجسيمي SRT عبارة عن تقنية فعالة في علاج الاورام الصغيرة أقل من 5 cm^3 و الجهاز العصبي و دماغ حيث أنها تمكننا من حماية OAR و عدد الحصص العلاجية قليل مقارنة بتقنيات العلاج الإشعاعي الأخرى   IMRT و 3DCRT و كذالك يمكن إستعمالها بدل الجراحة و العلاج الكيميائي

✓ **كلمات المفتاحية**

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