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External beam radiotherapy: Conventional and Stereotactic radiotherapy with LINAC

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Introduction

- Radiation therapy (RT) is a clinical modality dealing with the use of ionizing radiations in the treatment of patients with malignant and occasionally benign diseases.

- It has started since 1896 immediately after the discovery of of X-ray, but rapid technology advances began in the early 1950s, cobalt-60 machines and the invention of the linear accelerator.

- RT therapy can be delivered either **externally (**irradiation of patient from outside the body**)** or **internally** (brachytherapy, capsulated small source inside the patient cavities).

Overview:

- In this lecture basic concepts in radiation physics, radiation therapy treatment machines, and the dosimetry parameters used for photon external beam treatment will be discussed, emphasizing on two techniques Conformal 3D radiotherapy and Stereotactic radiosurgery irradiation.

- Overview of machine modelling, beam parameters, treatment planning and examples from clinical work will be shown.

Physics of radiation therapy

- Radiation is energy that comes from a source and travels through some material or through space (light, sounds, etc).

- Depending on radiation ability to ionize matter radiation is classified as:

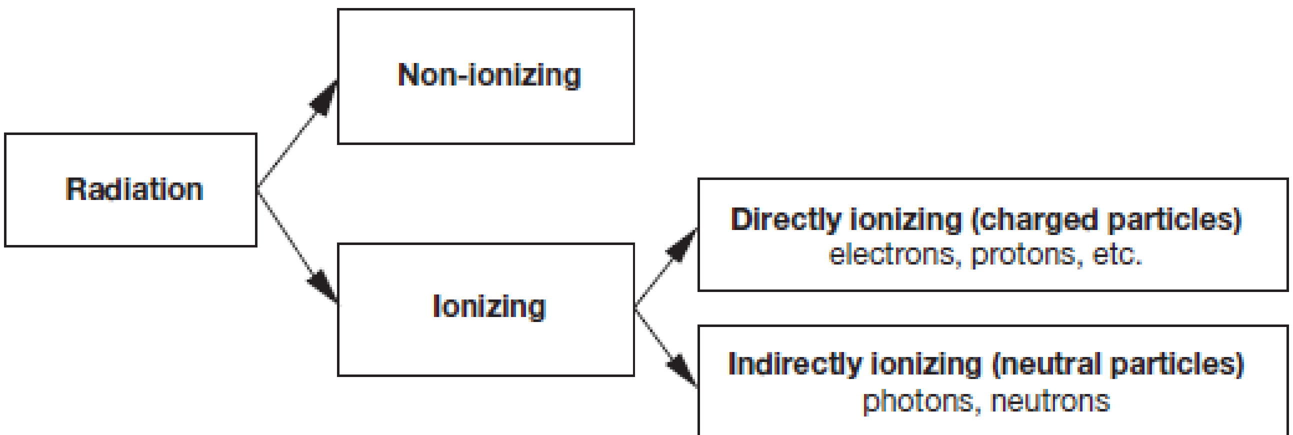


Fig.1 Scheme of calsification of radiation

➢ Ionizing radiation is any type of particle or *electromagnetic wave* that carries enough energy to ionize or remove electrons from an atom.

Photon interaction with matter

Elcromagnetic waves:
- X-rays
- gamma-rays

→

- **Photoelectric absorption** and **photoelectron production -** photon interacts with a tightly bound orbital electron of an attenuator and disappears)
- **Compton scattering (**a photon interaction with an essentially 'free and stationary' orbital electron)
- **Pair production (** in the nuclear and atomic fields)

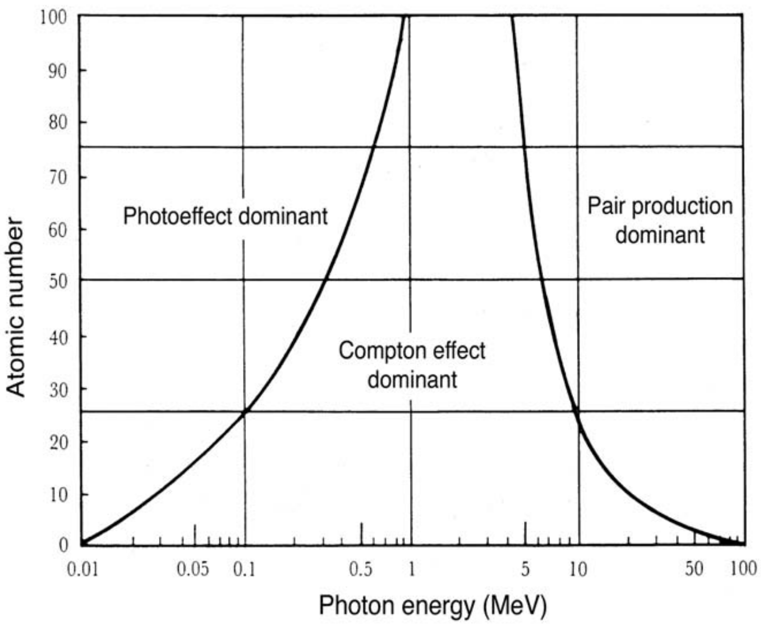


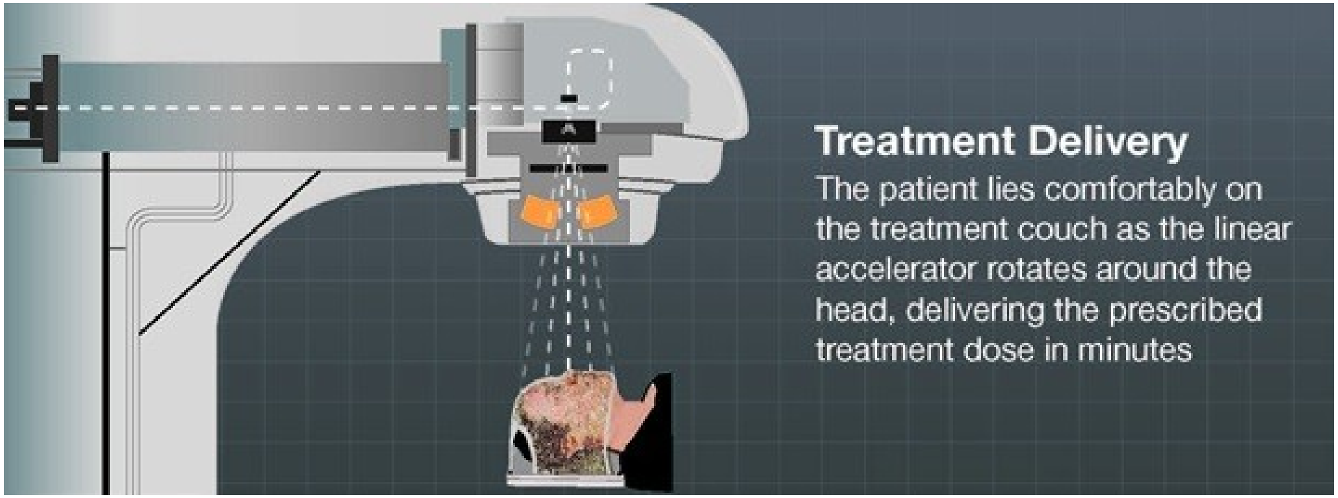
Fig 2.Regions of relative predominance of the three main forms of photon interaction with matter.

The energy is transferred to the medium when γ and x ray passing through a medium :

- If the absorbing medium consists of body tissues, sufficient energy may be deposited within the cells, destroying their reproductive capacity.

External beam radiation

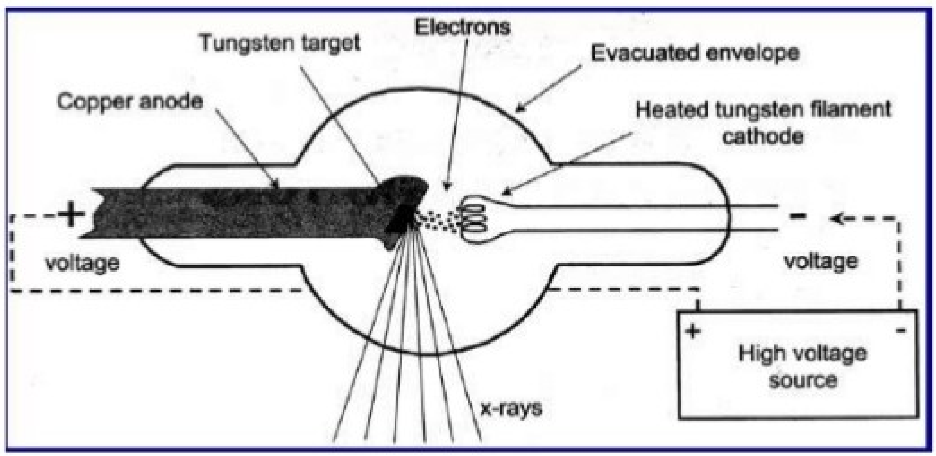
- External beam radiation is directed at the tumor from outside the body, mainly using photon beams, produced by a Co-60 teletherapy machines (high gamma emitting) or linear accelerators (high energy x-ray photon beams and electron beams produced).



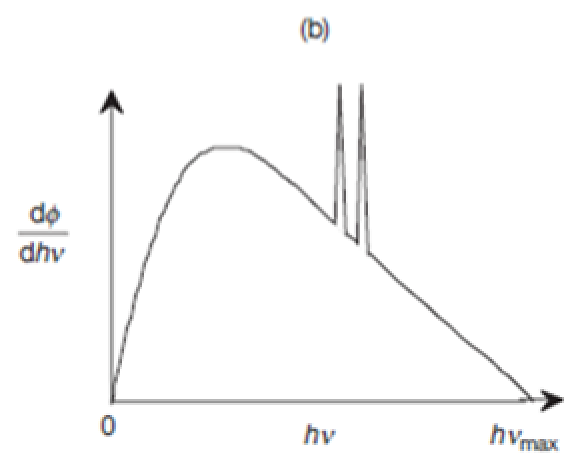
X-ray production

- High energy photon X- rays, which originate in a target bombarded with energetic electrons.

- The X rays from a target consist of bremsstrahlung photons, and characteristic photons. X rays are produced either in an X ray tube (superficial or orthovoltage X rays) or in a linac (megavoltage X rays).



Basic elements of an X Ray source assembly



(b) heterogeneous photon beams.

Photon beam characteristics

1.the photon radiation beam itself *in terms of the number and energies of photons constituting the photon beam*

2. ***and the other describes the amount of energy the photon beam may deposit in a given medium such as air, water or biological material.***

1.1 ***Photon fluence*** Φ (cm^{-2}) and photon fluence rate φ($cm^{-2}s^{-1}$) $\Phi = \frac{dN}{dA}$ $\varphi = \frac{d\Phi}{dt}$

1.2 ***Energy fluence*** (MeV/ cm^2)and energy fluence rate (MeV*cm^{-2}*s^{-1}) $\Psi = \frac{dE}{dA}$

1.3 ***The Air *kerma*** **in air (*Kair)air*** *at a* given point away from the source is proportional to *the energy fluence* Ψ or *photon fluence* Φ as follows:

$$K_{air} = \Psi\left(\frac{\mu_{tr}}{\rho}\right)_{air} = \Phi h\nu\left(\frac{\mu_{tr}}{\rho}\right)_{air}$$

-where $(\mu_{tr}/\rho)_{air}$ = mass–energy transfer coefficient for air at photon energy h*ν*

Kerma (J/kg) (called Gray Gy):***mean energy transferred*** from the *indirectly ionizing radiation* to **charged particles (electrons**) in the medium per unit mass d*m:*

$$K_{air} = \frac{dE_{tr}}{dm}$$

Photon beam characteristics

PENETRATION OF PHOTON BEAMS INTO A PHANTOM OR PATIENT

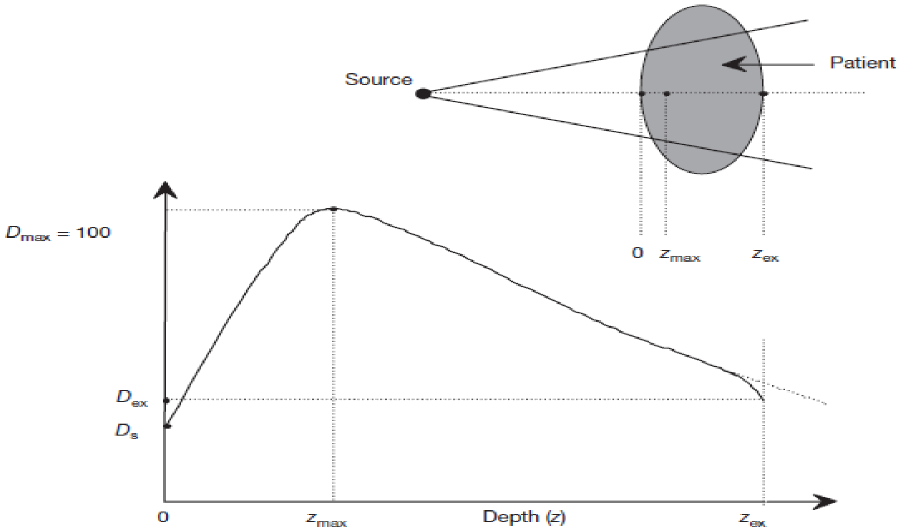


Fig 5 *Dose deposition from a megavoltage photon beam in a patient.* ***Ds*** *is the surface dose at the beam entrance side,* ***Dex*** *is the surface dose at the beam exit side.* ***Dmax i****s the dose maximum often normalized to 100,* ***resulting in a depth dose curve referred to as the percentage depth dose (PDD)*** *distribution. The region between z = 0 and z = zmax is referred to as the dose buildup region.*

The surface dose:

- Photons scattered from the collimators, flattening filter and air;Photons backscattered from the patient; High energy electrons produced by photon interactions in air and any,shielding structures in the vicinity of the patient.

✓ **Depth of dose maximum *zmax***

✓ **Buildup region** results from the relatively long range of energetic secondary charged particles (region form depth *z = 0 to depth z = zmax)(by* photoelectric effect, Compton effect, pair production)

Photon beam characteristics

2. Central axis depth dosess in water me ssd setup:

✓**Percentage depth dose -** Central axis dose distributions inside the patient or phantom are usually normalized to *Dmax = 100% at the depth of dose maximum zmax.*

✓**Tissue–air ratio- (TAR), Tissue–phantom ratio (TPR) and tissue–aMximum ratio (TMR)**

2.1 OFF-AXIS RATIOS AND BEAM PROFILES :

✓Dose distributions along the beam central axis give only part of the information required for an accurate dose description inside the patient. Dose distributions in 2-D and 3-D are determined with central axis data in conjunction with off-axis dose profiles

✓ **Beam flatness**The beam flatness *F is assessed by finding the maximum Dmax and* minimum *Dmin dose point values on the beam profile within the central 80% on* the beam width

✓**Beam symmetry**

Radiation Treatment machine parameters

✓External beam radiotherapy with photon beams is carried out with three types of treatment machine: -X ray units, -isotope teletherapy units (mainly 60-Counits) and LINAC.

✓ The main parameters in external beam dose delivery with photon beams are: *depth of treatment*; *field size* **(**square, rectangular, circular and irregular fields using jaws, conic collimators and shielding blocks MLCs*); source to axis distance* (SAD) in SAD (isocentric) set-ups or SSD set-ups; *photon beam energy*.

	Superficial	Orthovoltage	Co-60	4 MV	6 MV	10 MV	18 MV	25 MV
z_{max} (cm)	0	0	0.5	1	1.5	2.5	3.5	5

RT treatment machines-Linear accelerator

- High photon energy beams can be produced by accelerating electrons to high energies include linear accelerators, betatrons, and microtrons.

- Medical LINAC are cyclic accelerators that accelerate electrons to kinetic energies from 4 to 25 MeV .

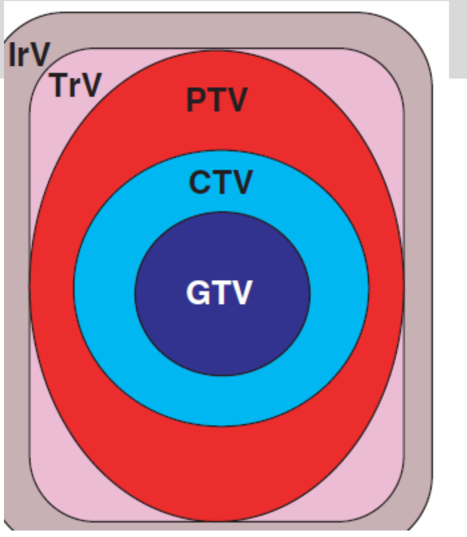
- In a linac the electrons are accelerated following straight trajectories in a special evacuated structures called accelerating waveguides.

- The accelerator Siemens Oncor Impression has been installed at Neurosurgery Service, University Hospital "Mother Teresa" in the begining of 2013.

Machine characteristics

- Siemens Oncor Impression Plus Medical Accelerator
- **Operational mode:** 6 MV flattened photon
- 7 MV unflattened photon
- **Asymmetric fields,** virtual wedge, physical wedge
- 6 electrons beams
- MLC: Optifocus with 82 leaves
- **EPID: Optivue**
- High precision treatment table, suitable for stereotactic radiosurgery

Principles of radiotherapy planning



▪**Target volume definition**

Criteria for delineating tumours for radiation is based on(ICRU) recommendations Report 50 (1993), 62 (1999) and 71 (2004).

▪Gross tumour volume (GTV) is the primary tumour or other tumour mass shown by clinical examination, by imaging.

■ Clinical target volume (CTV) - contains the GTV when present and/or subclinical microscopic disease that has to be eradicated to cure the tumour

■ Planning target volume taking itnto account patient oragn moves and the accuracy of positioning in treament machine. The PTV) is used in treatment planning to select appropriate beams to ensure that the prescribed dose is actually delivered to the CTV.

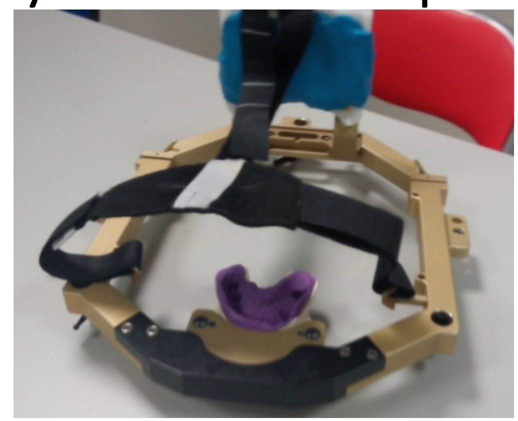
■ Treated volume-This is the volume of tissue that is planned to receive a specified dose and is enclosed by the isodose surface corresponding to that dose level, e.g. 95 per cent.

▪Conformity index-This is the ratio of PTV to the treated volume, and indicates how well the PTV is covered by the treatment while minimising dose to normal tissues.

Principles of radiotherapy planning

- **Organs at risk- These** are critical normal tissues whose radiation sensitivity may significantly influence treatment planning .

- **Immobilisation systems** are widely available for every anatomical tumour site and are important in reducing systematic set-up errors



  - *Complex stereotactic or relocatable frames* (e.g. Gill–Thomas) are fixed to the head by insertion into the mouth of a dental impression of the upper teeth and an occipital impression on the head frame.

  - *Perspex shells* reduce movement in head and neck treatments to about 2 mm.

▪CT imaging provides detailed cross-sectional anatomy of the normal organs, as well as 3D tumour information.

✓***These images provide density data for radiation dose calculations by conversion of CT Hounsfield units into relative electron densities using calibration curves.***

▪DRRs are produced from CT density information and are compared with electronic portal images (EPIDs).

CLINICAL TREATMENT PLANNING

✓ **dose computation is done using 3D computerised treatment planning systems which are programmed with beam data from therapy machines**

- **Conformal treatment** involves target volume delineation of tumour and normal organs according to ICRU principles with 3D dose calculations using MLC to shape beams.

- Complex treatment includes the use of IMRT to shape the fluence of the beam,dynamic treatments, IGRT and 3D or 4D delivery.

- **Stereotactic radiosurgery** treatment dose calcualtion based on tertiarycone collimators or micromultileafs to shape beams

Conformal 3D Radiotherapy

- Advances in imaging have been integrated with technological developments in radiotherapy delivery so that 3D planning of volumes has replaced 2D field arrangements.

- 3D conformal radiotherapy (CFRT) links 3D CT visualisation of the tumour with the capability of the linear accelerator to shape the beam both geometrically and by altering the fluence of the beam (IMRT).

- This encloses the target volume as closely as possible while reducing dose to adjacent normal tissues.

- Conformal therapy may involve the use of mixed beams combining photons and electrons for part of the treatment. Beams can be modified using bolus, wedges, compensators, MLCs and shielding blocks

3D conformal radiotherapy : Beam commissioning for Eclipse TPS(clinical implementation)

-3D Conformal Radiotherapy TPS Eclipse gives the possibility of 3D visualisation of the tumour and this combined with the capability of the **linear accelerator** to shape the treatment field makes possible an optimal dose conformity.

❖Requested dosimetric measurements for algorithm AAA:

- Diagonal profiles
- Beam profiles
- Percentage depth doses
- Absolute dose

❑Dosimetric Equipment used :

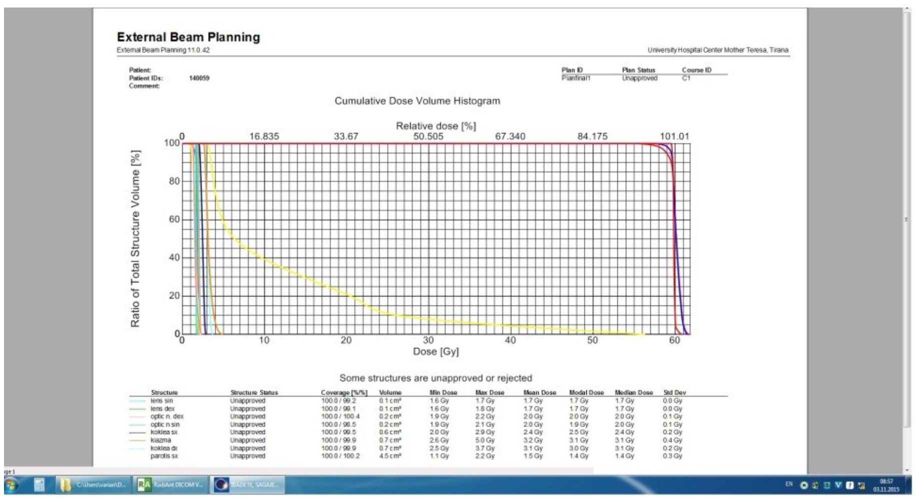
- ➢3D water phantom
- ➢L8 linear array
- ➢ Octavious 2D array
- ➢Semiflex ionisation chamber
- ➢Roos chamber.

-6X-Beam data profiles in different depths inserted in TPS Eclipse

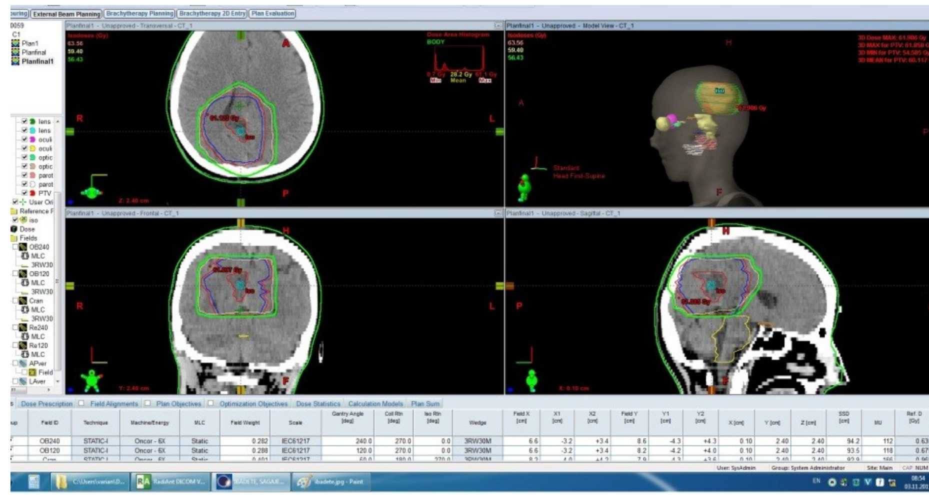
CNS radiotherapy treatment plan (clinical example)

GBM post op

Dosis 59.4 Gy/ 33 fractions



Dose volume histogram



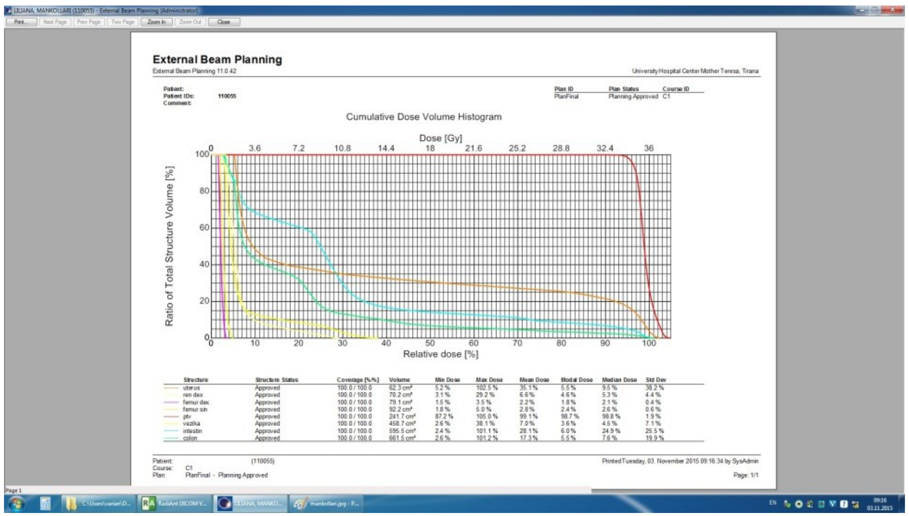
Dose distribution on images in axial, coronal and saggital planes

✓The normalization was 100 % in the isocenter and the isodosis of 95% covers the PTV (ICRU) .The beam arrangement was two wedged posterior oblique equally weighted fields and one vertex field.

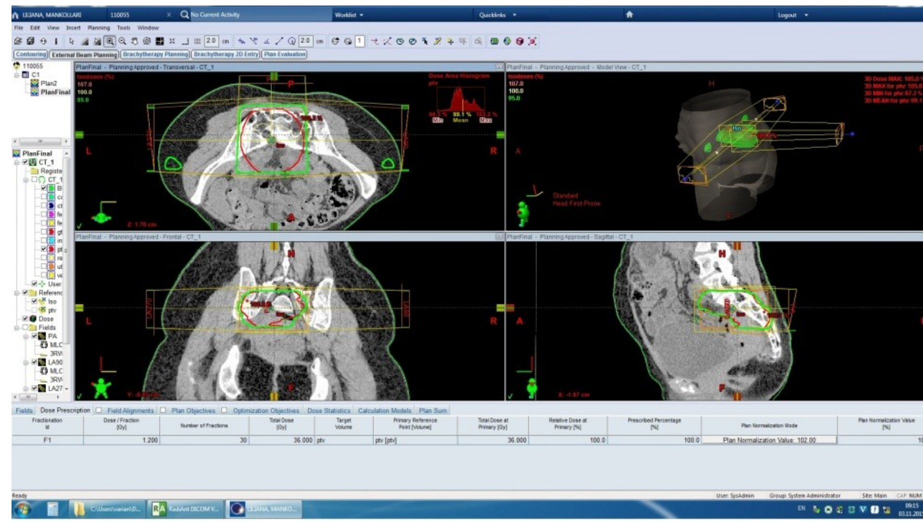
Pelvic radiotherapy treatment plan (clinical example)

Local recidive CA rectal /reirradiation

Dosis 36 Gy / 30 sesions



Dose volume histogram



Dose distribution on images in axial, coronal and saggital planes

- CT-imaging: prone position
- RT beam arrangment: two lateral and one PA wedged beam, the normalization was 100% to the isocenter and the isodosis 95% covers the PTV.

✓This treatment was hiper-fracctionationed (two sessions a day with 1.2 Gy/ session with minimum 6 hours difference)

Stereotactic radiosurgery (SRS)

- Stereotactic radiosurgery (SRS) delivers high doses of radiation to treat tumors (12 gy-25 Gy) with great precision , commonly used for tumors the brain or central nervous system (CNS).

- SRS is a technique using multiple *noncoplanar arcs of circularly* collimated x-ray beams directed to the linac isocentre.

- **Request** high accuracy of dose delivering including *patient positioning* (1 mm) using a stereotactic frame attached to the patient's skull.

- QA that includes machine QC and optimization of treatment plans.

- In September 2013 the radiosurgery treatment plan X-Knife was **commisioned** and the intracranial radiosurgery treatments started.

Stereotactic radiosurgery : Beam commissioning for Integra X-knife TPS (clinical implementation)

-Dosimetric data performed in comissioning the LINAC with tertiar conic colllimators (a set of 12 circular collimators with diameter in range 12.5 mm to 40 mm, step 2.5 mm) for Integra X-Knife TPS, were:

✓ **Output factors**,

✓ **OARs and TMR**

-Dosimetric Equipments nedded:

✓ MP3 water phantom,

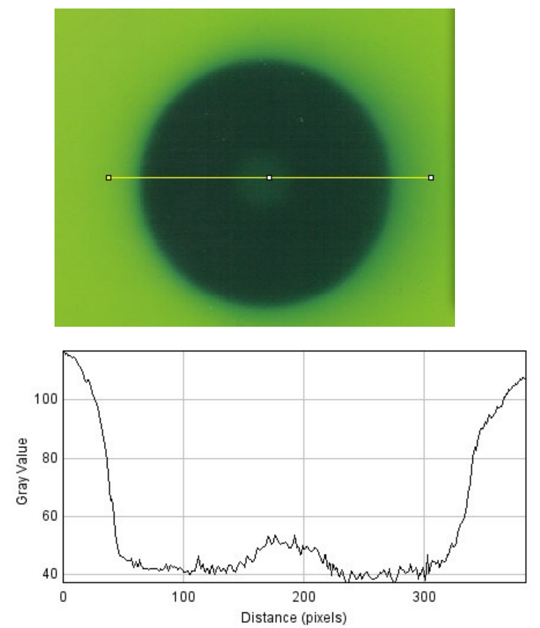
✓ Pin point chamber ,

✓ Semiflex for reference dose,

✓ Multidos and Unidos Eelectrometer.

▪ Winston–Lutz test (Lutz et al. 1988). Control the mechanical and radiation congruence for isocenter check .Is carried out using a circular collimator 25 mm as shown in the figure.

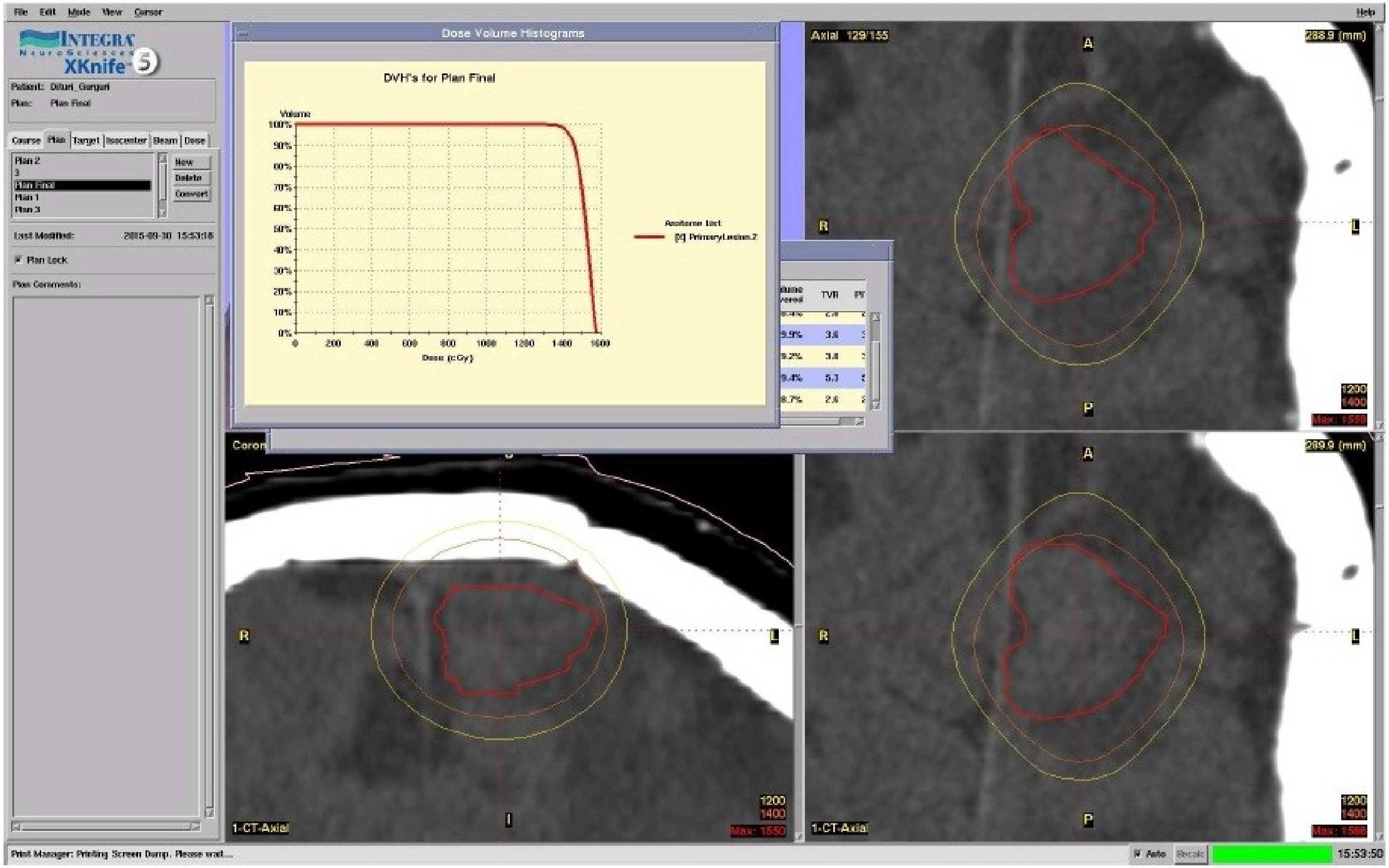
▪With a circular applicator attached to the head of the machine and a pinball bearing suspended at the isocentre, the gantry may be rotated and films exposed at appropriate angles. Rotation of the couch and collimator can also be included



Winston-Lutz test with Gafchromic film

Sterotactic radiosurgery treatment planing with integra X-Knife

- Metastasis from breast cancer with prescribed dose to 14 Gy to the 90 % isodose



Dose distribution on CT images, axial coronal sagittal planes and DHV

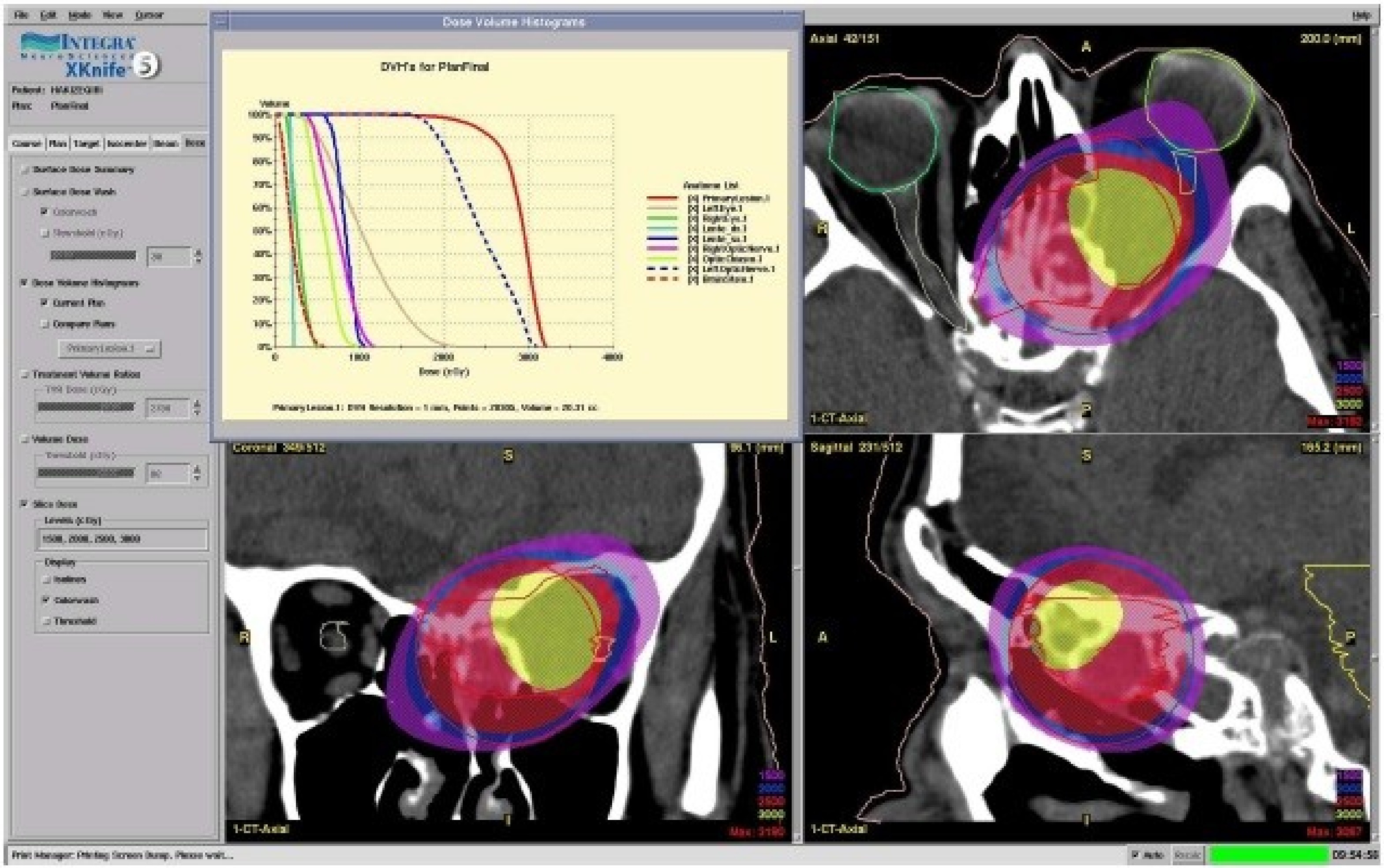
Fractionated Stereotactic Radiosurgery

- Fractionated stereotactic radiosurgery is a process in which the total dose of stereotactic radiation is divided into several smaller doses of radiation on separate days of treatment ranging from two to five treatments.

- General used for treating benign disease as menignioma, swhanoma, etc. We have started using fractionated radiosurgery on January 2015.

Sterotactic Fractionated radiosurgery treatment planing with integra X-Knife

- Meningioma with prescribed dose to 25 Gy/5 fractions to the 90 % isodose



Conclusions

- Single fraction Radiosurgery
- Fractionated Radiosurgery
- 3D- Conformal Radiotherapy

The goal in radiotherapy is to get a higher quality treatments.

Thank you for your attention