Special Techniques

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Slides from E. Podgorsak. PhD

TOTAL BODY IRRADIATION

- Total body irradiation (TBI) is a special radiotherapeutic technique that delivers to a patient's whole body a dose **uniform to within ±10%** of the prescribed dose.
- Megavoltage photon beams, either cobalt-60 gamma rays or megavoltage x rays are used for this purpose.
- In broader sense, TBI techniques encompass:
  - Irradiation of the whole body
  - Half body irradiation
  - Total nodal irradiation

Clinical TBI categories

- Categories of TBI depending on clinical situation:
  - High dose TBI, with dose delivery in a single session (dose: 750 to 900 cGy) or in up to **six fractions of 200 cGy each in 3 days (total dose: 1200 cGy).**
  - Low dose TBI, with dose delivery in 10 to 15 fractions of 10 to 15 cGy each.
  - Half-body irradiation, with a dose of 8 Gy delivered to the upper or lower half body in a single session.
  - Total nodal irradiation, with a typical nodal dose of 40 Gy delivered in 20 fractions.

TBI treatment

- TBI is used **primarily** as part of a preparatory **cytoreductive conditioning regimen prior to bone marrow transplantation (BMT).**
- The conditioning regimen may be based on chemotherapy alone; however, the most common pre-transplant conditioning is a combination of high dose chemotherapy and TBI.
- TBI results in immuno-suppression, which helps prevent the failure of the BMT.

Diseases treated with TBI

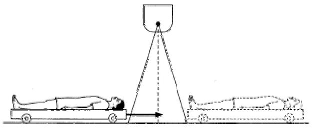
- Diseases treated with bone marrow transplantation are:
  - Various types of leukemia (acute non-lymphoblastic leukemia, acute lymphoblastic leukemia, chronic myelogenous leukemia)
  - Malignant lymphoma
  - Aplastic anemia
- High dose TBI has been used as adjuvant therapy in treatment of: Ewing's sarcoma and non-Hodgkin's lymphoma.
- Low dose TBI is used in treatment of: lymphocitic leukemia, lymphoma and neuroblastoma.
- Total nodal irradiation is used as adjuvant treatment of autoimmune diseases.

Technical aspects of TBI

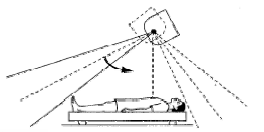
- Megavoltage photon beams:
  - Cobalt-60 machines
  - Linear accelerators (linacs)
- The beams can be:
  - Stationary: encompassing the whole patient extended distances and maximum field size
  - Moving, with smaller field sizes, in some sort of translational or rotational motion to cover the whole patient with the radiation beam.
- Usually, parallel-opposed irradiations are used by delivering each fractional dose in two equal installments and switching the patient's position between the two installments.

Total body irradiation techniques

Treatment with a translational beam



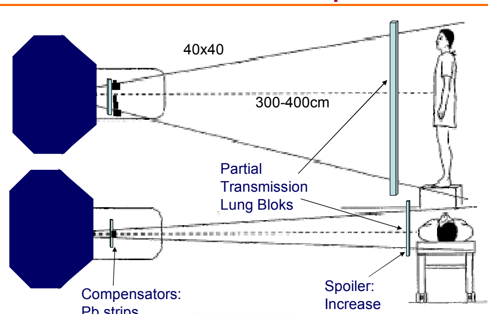
or sweeping beam.



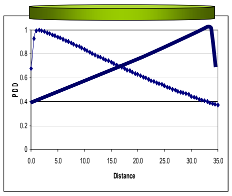
Dose prescription point

- The TBI dose is usually prescribed to the patient's midplane at the level of the umbilicus.
- Deliver prescribed dose with a <u>+</u>10% uniformity within the whole body.
- Dose Uniformity is achieved with the use of bolus, partial attenuators, and/or compensators.
- **AP/PA** fields promote a more uniform dose than lateral fields

Patient Setup

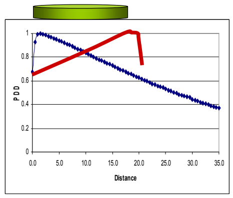


AP/PA vs. LATERALS



Thickest part of patient (laterals) = 35 cm.

Rx to midline of 100 cGy, maximum dose is 142 cGy



Thickest part of patient (laterals) = 20 cm.

Rx to midline of 100 cGy, maximum dose is 110 cGy

Achieving Dose Uniformity

- AP/PA
- Higher Energy (higher PDD curve)
- Extended SSD (higher PDD curve)

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Considerations for TBI

- Dose is 1000-1200 cGy
- Fractionated 4-8 fractions
- Prescribed at umbilicus (normally thickest part of body)
- Machine dose rate reduced to deliver 5-15 cGy/min at patient's midline
- SMD is usually 300-400 cm
- Doses to lung limited to 600-800 cGy
  - partial transmission blocks (limit risk of pneumonitis)
- Skin dose increases with Field Size, SSD and use of spoilers

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TBI Dose Verification

1. TLDs
2. DIODES
3. LOCATION
   - Head, Neck, Shoulder, Chest/lung
   - Umbilicus, Hip, Thigh, Ankle

TBI Questions

- What type of radiation do you use for TBIs?
- What dose uniformity do you want to achieve?
- How can you achieve dose uniformity?
- What is the fractionation scheme for TBIs?
- What can you treat with TBI?
- What is the dose limiting factor for TBIs?
- How can you improve skin dose?
- Where is the prescription point?
- How does one perform in vivo measurements for TBI?

TOTAL SKIN ELECTRON IRRADIATION

- Total skin electron irradiation (TSE):
  - Aim is to irradiate the patient's whole skin with the prescribed radiation dose
- Uses high dose rate electrons of 6 or 9 MeV
- Treatment of mycosis fungoides and T-cell lymphoma

TOTAL SKIN ELECTRON IRRADIATION

A patient with mycosis fungoides treated with TSEI

Before treatment

After treatment

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TOTAL SKIN ELECTRON IRRADIATION

- Photon contamination of the electron beam
- Treatment fields are angled to reduce the photon dose to the patient.
- Finger nails, toe nails, and the eyes are dose limiting sites
- The typical dose/fractionation regimen for TSE is 36 Gy in 18 fractions.
- (sometimes 20 fractions delivery up to 40 Gy)

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Current TSE irradiation techniques

- Translational techniques, in which the patient is translated on a stretcher through an electron beam of sufficient width to cover the patient's transverse dimensions.
- Large electron field techniques, in which a standing stationary patient is treated at a large SSD with a single large electron beam or a combination of large electron beams. (most commonly used → Stanford Technique)
- Rotational techniques, in which the patient is standing on a rotating platform in a large electron field.

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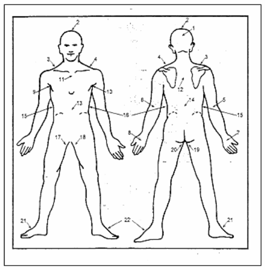
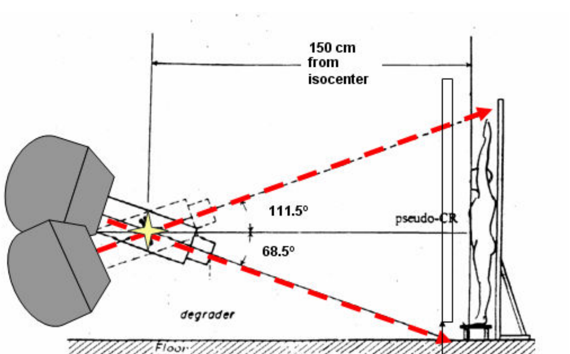
Dosimeter Placement



Number	Location
1	Scalp
2	Scalp vertex
3	Top of right shoulder
4	Top of left shoulder
5	Right elbow
6	Left elbow
7	Right hand (mid dorsum)
8	Left hand (mid dorsum)
9	Right axilla
10	Left axilla
11	Upper thorax
12	Upper back
13	AP abdomen
14	PA abdomen lower back
15	Right abdomen
16	Left abdomen
17	Right upper medial thigh
18	Left upper medial thigh
19	Right buttock
20	Left buttock
21	Right foot (mid dorsum)
22	Left foot (mid dorsum)
23	Rt Breast (beneath)
24	Lt Breast (beneath)
25	

The treatment intent is to deliver 200 cGy prescribed dose to the umbilicus.
TLD packs were taped to the skin surface at the positions indicated above.



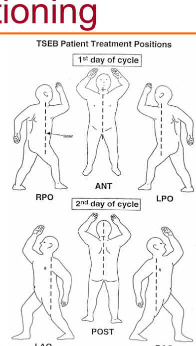
CAX of beams above and below patient to reduce x-ray dose to patient (x-ray contamination peaks along central axis)

Spoiler: 10 cm from patient

Patient Positioning

Stanford Techniques uses six fields:

- Anterior
- Posterior
- Four obliques
- Positioned 60 degrees around the circumference of the patient
- Three fields treated per day



Patient Positioning

A complete cycle of 12 patient positions and gantry angle combinations make one complete treatment. Setup at CTRC is as follows:.

Field No.	TREATMENT POSITION	G ANGLE
1	LEFT POSTERIOR OBLIQUE (lt side toward machine, 60° turn)	111.5
2	LEFT POSTERIOR OBLIQUE (lt side toward machine, 60° turn)	68.5
3	ANTERIOR (facing machine)	68.5
4	ANTERIOR (facing machine)	111.5
5	RIGHT POSTERIOR OBLIQUE (rt side toward machine, 60° turn)	111.5
6	RIGHT POSTERIOR OBLIQUE (rt side toward machine, 60° turn)	68.5
7	RIGHT ANTERIOR OBLIQUE	68.5
8	RIGHT ANTERIOR OBLIQUE	111.5
9	POSTERIOR	111.5
10	POSTERIOR	68.5
11	LEFT ANTERIOR OBLIQUE	68.5
12	LEFT ANTERIOR OBLIQUE	111.5

TSE

- X-ray contamination can be a limiting factor
- X-ray contamination is peaked on central axis
- Higher doses occur at curved surfaces
- Low doses at areas under skin folds
- Very long treatment times
- Eye lids and nails are shielded with lead
- Electron Boosts are made to the perineum, soles of the feet, under skin folds and to the scalp (usually with 6 MeV)
- Spoiler is used to increase scatter of electrons and decrease energy (increase skin dose)

TSE Calibration

- Measurements made with Plane parallel chamber in a solid water phantom
- Output measurements made under clinical conditions to determine dose rate, optimal gantry angles for treatment and the number of MU to deliver prescribed dose of 200 cGy per field

TSE Technique at CTRC

- Large electron fields produced by scattering electrons through wide angles and using large treatment distances (2.5 m)
- Spoiler and tray used to reduce energy
- 9 MeV electrons
- Dose prescribed to 1 cm deep
- Not to exceed bone marrow tolerance
- 36 Gy delivered in 9 weeks using Stanford Technique
  - 400 cGy per week
  - 200 cGy per fraction over two days due to patient positioning & time
- Dose uniformity: Vertically ±8% & Horizontally ±4%
- Boosts to axilla, perineum, breast, folds and soles of feet
- Shield eyelids, finger and toenails
- Verify patient dose using Mosfets or TLDs

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TSE Questions

- What do you need to calibrate the linac to do TSE?
- Describe the Stanford Technique
- What is the fractionation scheme?
- What is the effect of a spoiler?
- How is dose delivered verified with in vivo measurements?
- How is the dose from x-ray contamination reduced?
- Where is x-ray contamination significant?
- What are the uniformity goals?
- What is treated with TSE?

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STEREOTACTIC IRRADIATION

- Stereotactic irradiation comprises **focal irradiation** techniques that use **multiple, non-coplanar** photon radiation beams and deliver a prescribed dose of ionizing radiation to pre-selected and stereotactically localized lesions.
- The lesions are primarily in the **brain**; however, the technique has been used on other parts of the body.
- Characteristics of Stereotactic Irradiation is **small treatment volumes** and **rapid dose fall off.**
- Stereotactic irradiation may be delivered with **one** or **several** external radiation sources.

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STEREOTACTIC IRRADIATION

- Stereotactic radiosurgery in which the total dose is delivered in a single treatment session.
- Stereotactic radiotherapy in which the total dose is delivered in multiple fractions, similarly to standard radiotherapy.
- From a technical point of view there is essentially no difference between stereotactic radiosurgery and stereotactic radiotherapy, and often the term radiosurgery is used to describe both techniques.

Characteristics of Stereotactic Irradiation

- The main characteristics of stereotactic irradiation are:
  - The total prescribed doses are of the order of 10 - 50 Gy
  - The planning targets are small, with typical volumes ranging from 1 to 35 cm^3.
  - The requirements for positional and numerical accuracy in dose delivery are $\pm$ 1 mm and $\pm$5 % respectively.
  - Essentially any radiation beam that has been found useful for external beam radiotherapy has also found use in radiosurgery
    - cobalt-60 gamma rays,
    - megavoltage x rays
    - proton and heavy charged particle beams
    - neutron beams

Physical requirements for radiosurgery

- Physical requirements for radiosurgery are:
  - Accurate determination of the target volume and its location with stereotactic techniques.
  - Calculation of 3-D dose distributions inside and outside the target.
  - Calculation of dose-volume histograms (DVHs) for the target and specific sensitive organs surrounding the target.
  - Dose distributions that conform to target shape and give a sharp dose fall-off outside the target volume.
  - Direct superposition of isodose distributions on diagnostic images, showing the anatomical location of the target.

Clinical requirements for radiosurgery

- Clinical requirements for radiosurgery are:
  - Accurate knowledge of the total dose and fractionation scheme required for treatment of a particular disease.
  - Accurate positional (within ± 1%) delivery of dose to the pre-determined target.
  - Accurate numerical (within ± 5%) delivery of dose to the pre-determined target.
  - Low skin dose (to avoid epilation) and low eye lens dose (to avoid cataract formation).
  - Low or negligible scatter and leakage dose to radiosensitive organs (to avoid subsequent somatic and genetic effects)

Diseases treated with stereotactic irradiation

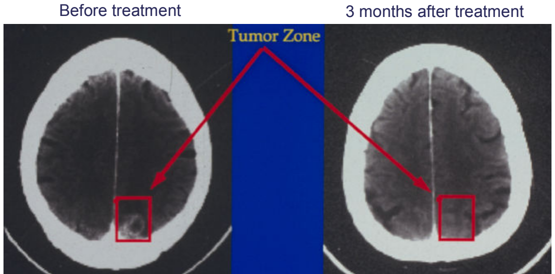
The diseases treated with stereotactic irradiation fall into one of five categories:

- Functional disorders: trigeminal neuralgia - Parkinson's disease - epilepsy - intractable pain - psychoneurosis
- Vascular lesions: arteriovenous malformation (AVM) - - acoustic neuroma - cavernous angioma - arterial neurism
- Primary benign tumors: pituitary adenoma - meningioma - chordoma - craniopharyngioma - meningioblastoma
- Primary malignant tumors: glioblastoma multiforme (GBM) - pineal tumor -medulloblastoma - lymphoma
- Metastatic tumors

Diseases treated with stereotactic irradiation

- Metastatic disease treated with stereotactic radiosurgery

Before treatment 3 months after treatment



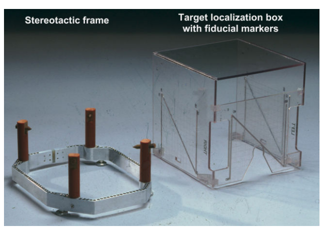
Equipment used for stereotactic radiosurgery

Equipment for stereotactic radiosurgery:

- Stereotactic frame: defines a fixed coordinate system for an accurate localization and irradiation of the planning target volume (PTV).
- Imaging equipment (CT, MRI and DSA) with which the structures, lesions and PTVs are visualized, defined and localized.
- Target localization software: used in conjunction with the stereotactic frame system and imaging equipment to determine the coordinates of the target in the stereotactic reference system.
- Treatment planning system: calculates the 3-D dose distribution and superimposes it onto the patient's anatomical information.
- An appropriate radiation source and radiosurgical treatment technique.

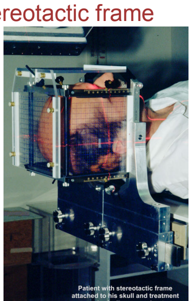
Equipment used for stereotactic radiosurgery

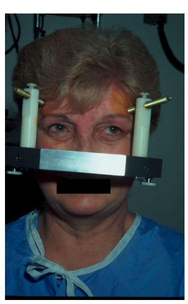
- Stereotactic frame



Equipment used for stereotactic radiosurgery

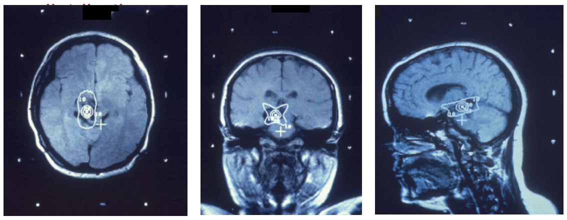
- Stereotactic frame





Equipment used for stereotactic radiosurgery

- Stereotactic frame, fiducial markers and dose



The white dots in the images are the fiducial markers resulting from the Intercept of CT slice with the fiducial marker plates.

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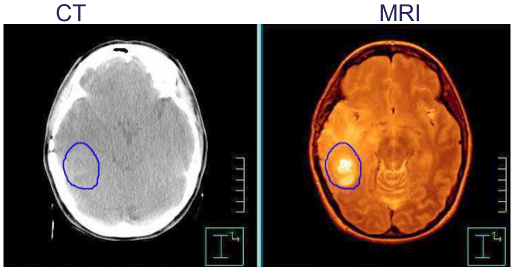
Equipment used for stereotactic radiosurgery

- Imaging for target localization: CT and MRI

CT MRI



For soft tissue contrast

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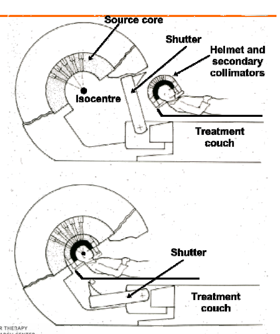
Radiosurgical techniques

Main components of the Gamma Knife:

- Source core
- 201 30Ci cobalt-60 sources
- Shutter mechanism
- Helmet and secondary collimators (circular fields with diameters of 4, 8, 14, and 18 mm.
- Treatment couch
- SAD is 40cm



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Gamma Knife

- "Gold Standard" for Radiosurgery
- Rx to 50% isodose line (in contrast to linac Rx of 90 %)
- Advantages over other systems
  - Accuracy
  - Field shaping through the use of plugs
  - Efficient QA
  - High isocenter accuracy (<0.3 mm uncertainty)
  - Smaller penumbra than linac based SRS
- Disadvantages
  - NRC regulated
  - Source replacement every 7-10 yrs
  - Treats only tumors of 4 cm or less in diameter
  - No fractionation
  - Only for cranial applications and very expensive

Linac-based Radiosurgery

- Linac-based radiosurgery delivers a narrow collimated x-ray beam while rotating around a target.
- The target is positioned at isocenter.
- The target is caught in a crossfire of x-ray beams which deliver a lethal dose to the target and a sublethal dose to the surrounding normal tissues

Linac-based Radiosurgery

Linac-based radiosurgery falls into three main categories:

1. Radiosurgery with modified isocentric linac
   - Moving beam techniques such as **Multiple non-coplanar converging arcs**
   - Multiple stationary beams in conjunction with miniature MLC
2. Miniature linac mounted on robotic arm (CyberKnife)
3. Miniature linac mounted on CT gantry (Tomotherapy)

Linac-based Radiosurgery

Modifications to standard isocentric linacs for radiosurgery.

The modifications are relatively simple and consist of:

- Supplementary collimation
  - Set of collimators to define small diameter beams
  - Or with a miniature MLC to define small area irregular fields
- Remotely controlled motorized table or treatment chair rotation.
- Table brackets or a floor stand for immobilizing the stereotactic frame during treatment.
- Special brakes to immobilize the vertical, longitudinal and lateral table motions during treatment.
- Interlocked readouts for angular and height position of the couch.

Linac-based Radiosurgery

General aspects of radiosurgery with isocentric linacs:

- Most linac based radiosurgery procedures are carried out on modified isocentric linac used for standard radiotherapy.
- The requirements on mechanical stability of linacs are even more stringent in radiosurgery than in routine radiotherapy.
- The most important requirement of an isocentric linac used for radiosurgery is the mechanical stability and accuracy of its isocenters.

Linac-based Radiosurgery

Linac isocenters in radiosurgery

- For linac based radiosurgery the diameter of the isocenters sphere must not exceed 1 mm.
- The uncertainty on the radiosurgical linac isocenters is of the same order of magnitude as the target localization accuracy achievable with modern imaging techniques, such as CT, MRI, and DSA.

Linac-based Radiosurgery

Stereotactic frame attached to floor stand

Stereotactic frame attached to treatment couch

Linac-based Radiosurgery

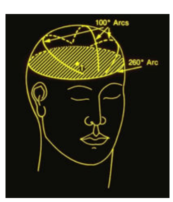
Collimation for linac-based radiosurgery

- Most linac based radiosurgical techniques use circular radiation beams which are produced by special cones attached to the head of the linac.
- The circular beams are usually between 10 and 40 mm in diameter at the linac isocenters and are produced by 10 cm thick lead cylinders with appropriate circular holes drilled along their axes.
- The use of the original rectangular linac collimators for defining the small radiosurgical beams is not recommended.

Linac-based Radiosurgery

Multiple non-coplanar converging arcs technique:

- The target dose is delivered through a series of gantry arcs, each arc with a different stationary position of the treatment couch or chair.
- The arc angles are usually smaller than 180° to avoid parallel-opposed beams in the plane of the arc.
- Typical number of arcs used ranges from 4 to 11.
- The image on the left uses 4 arcs



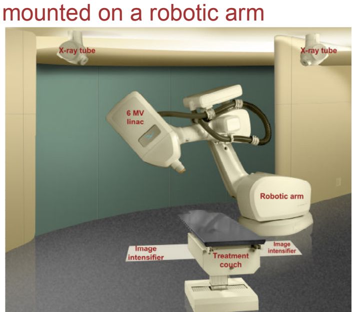
CyberKnife

Miniature linac on a robotic arm (CyberKnife):

- This radiosurgical technique uses:
  - A miniature 6 MV linac instead of a conventional isocentric linac. The miniature linac operates in the X band and is mounted on an industrial robotic manipulator.
  - Non-invasive image guided target localization, instead of the conventional frame based stereotaxy.
- The image-guided frameless radiosurgery system achieves the same level of targeting precision as the frame-based radiosurgery.

CyberKnife

Miniature linac mounted on a robotic arm



Courtesy of Accuray Inc., Sunnyvale, CA

CyberKnife

- In comparison with standard radiosurgical techniques, the CyberKnife offers the following advantages:
  - It allows **frameless radiosurgery**, i.e., it dispenses with the need for a rigid and invasive stereotactic frame.
  - It **monitors and tracks the patient's position continuously** and uses on-line images for finding the exact position of the target in the treatment room coordinate system.
  - It aims the radiation beam into the on-line determined target position and achieves a **dose delivery accuracy** of the order of **1 mm** through this image-guided dose delivery method.
  - It allows for frameless radiosurgical dose delivery to **extracranial targets**, such as the spine, lung and prostate.

CyberKnife

- Industrial Robot arm with Linac head allowing 6 degrees of freedom
- Standing wave guide with no bending magnet or flattening filter
- 400 MU/min dose rate delivery (new model up to 600)
- 5-60 mm collimator sizes
- Two orthogonal x-ray cameras mounted on ceiling
- Two amorphous silicon detectors mounted flush with floor
- Image guided setup and treatment
- Robot automatically corrects for patient motion during treatment
- Real-time respiratory motion tracking

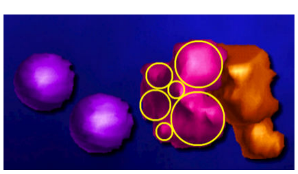
Radiosurgical targets

- Spherical target
  - Circular field - Single isocenter
    - Possible with Γ Knife and Linac-based radiosurgery
- Irregular target
  - Circular fields and Multiple isocenters - Conformal radiosurgery
    - Possible with Γ–Knife and Linac-based radiosurgery
  - Irregular uniform intensity fields - Conformal radiosurgery
    - Only possible with linac equipped with micro-multileaf collimator (micro-MLC)
  - Irregular intensity modulated fields - IMRS
    - Only possible with linac equipped with micro-multileaf collimator (micro-MLC)

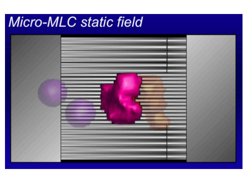
Radiosurgical techniques

Irregular targets in radiosurgery:

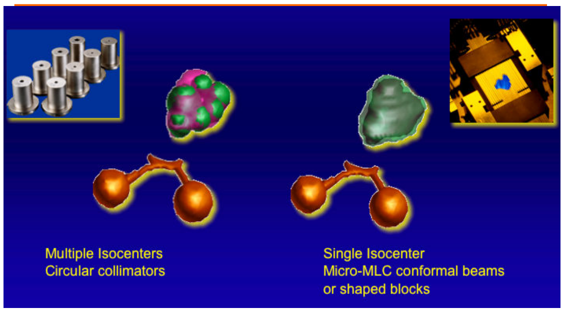
Multiple isocenters fields



Micro-MLC irregular



Irregular targets in Radiosurgery

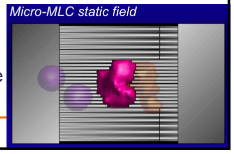


Courtesy of:
BrainLAB Heimstetten, Germany

Micro-MLC in linac-based radiosurgery

- Micro-MLCs uses multiple stationary fields that conform to the target shape.
- Advantages over the multiple isocenters approach:
  - Improved dose homogeneity inside the target
  - Sharper dose fall-off outside the target
  - Less time-consuming treatment planning
  - Shorter treatment time
  - Simpler treatment
  - Significantly lower scatter and leakage dose to the patient.

Micro-MLC static field



SRS machine acceptance test

- Hardware installation verification:
  - Cone attachments, MLC attachments, table attachments, non-docked systems
- Verify isocenter sphere of radius of 1 mm
- Verify stable output
- Measure PDD with small ion chamber or film
- Measure output factors with small chamber or film or diodes
- Measure profiles with film or small chamber.
  - Penumbra region use film or diodes

QA Schedule for Gamma Knife

- Daily
  - Emergency interlocks
  - Interlocks
  - AV equipment
- Monthly
  - Output ($\pm$ 2%)
  - Timer tests (Constancy, linearity, on/off error)
  - Frame accuracy
  - TPS testing
  - Table/couch test
  - Daily tests

QA Schedule for Gamma Knife

- Semi-Annual
  - Leak test (<0.005 μCi)
- Annual
  - Daily & Monthly Tests
  - Helmet factors ($\pm$3%)
  - Profiles
  - Isocenter (sphere with radius of 1mm)
- Imaging and TPS
  - CT accuracy (monthly)
  - MRI & PET accuracy (monthly & for each pt)

QA Schedule for Linac-based SRS

- Daily
  - Couch mounted frame & laser alignment
- Weekly
  - Laser alignment
- Biweekly
  - X-ray/light field alignment
- Monthly
  - Patient support assembly
  - Output
- Quarterly
  - Arc therapy
- Annually
  - Isocenter alignment
  - Stability of beam support

Uncertainty in radiosurgical dose delivery

- The minimum uncertainty in target localization achievable with modern imaging equipment combined with stereotaxy is of the order of **±1 mm**.
- The possible motion of brain tissues when moving the patient from the imaging equipment to the therapy machine is of the order of a fraction of a millimeter.
- The measured uncertainty in radiosurgical dose delivery is:
  - Of the order of ± 0.5 mm for a linac in a superb mechanical condition.
  - Of the order of ±0.3 mm for the Gamma Knife.

SRS & SRT

Stereotactic radiosurgery (single session treatment):

- Prescribes doses of 12 - 25 Gy
- The larger is the target, the lower is the prescribed dose.

Stereotactic radiotherapy (fractionated treatment):

- Typical dose fractionation regimes are:
  - 6 fxns x 7 Gy/fxn (total dose: 42 Gy) with treatment given every second day.
  - 10 fxns x 4 Gy/fxn (total dose: 40 Gy), with treatment given daily.

Dose prescription and dose fractionation

Target dose conformity and homogeneity:

- In standard radiotherapy, target dose homogeneity is very important and ideally lies within ±5 %of the prescribed dose.
- In radiosurgery, dose conformity to the relatively small target volume is extremely important and the **target dose homogeneity requirement is often relaxed** to allow for optimization of the target dose conformity.
- The dose is then prescribed to the lowest isodose surface which still covers the target volume and a target dose inhomogeneity may amount to 100%.

Questions

- What typical tumor sizes are treated with SRS?
- In SRS, how are the isodose distributions manipulated to provide conformal coverage?
- Which SRS technique is beast suited to treat large targets? Only small targets?
- For linac-based SRS, the isocenter is described as a sphere not to exceed a radius of ___mm
- Linac-based SRS uses what types of collimation for the stereotactic fields?
- Describe advantages and disadvantages of using a Γ knife vs. Linac based SRS system.
- What beam delivery techniques are used by Linac-based SRS?

Questions

- Are there any advantages between microMLC and cone-attachment SRS LINAC treatments?
- What is the uncertainty required for dose delivery?
- What is the uncertainty in positional accuracy?
- How does Γ knife treat irregular tumors? Is there a size limit?
- Define SRS and SRT
- What conditions are treated with SRS?
- What imaging techniques are used with SRS planning?
- What radiation modalities are used for SRS?

Intraoperative Radiotherapy

- Intraoperative radiotherapy (IORT) is a special radiotherapeutic technique that delivers in a single session a radiation dose of the order of 10 - 20 Gy to a surgically exposed internal organ, tumor or tumor bed.
- IORT combines two conventional modalities of cancer treatment: surgery and radiotherapy.
- The IORT team consists of a surgeon, radiation oncologist, medical physicist, anesthesiologist, nurse, pathologist and radiation therapist.

Intraoperative Radiotherapy

- Historically, tissues within the retroperitoneum, including the pancreas, rectum and stomach have been most commonly treated with IORT, and, on a smaller scale, bladder, breast and gynecological malignancies.
- Often both the operating room and the radiation treatment room are merged into one, resulting in a specially shielded operating suite in which a dedicated radiation treatment unit is installed permanently.
- Three beam modalities are used for IORT:
  - Orthovoltage x rays
  - Megavoltage electrons
  - High dose rate brachytherapy with iridium-192 source.

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Intraoperative Radiotherapy

- To improve the local and regional control a large radiation dose is delivered during the surgical procedure.
- The main biologic **advantage** of the IORT is its ability to decrease normal tissue toxicity by displacing or shielding sensitive structures from the radiation beam.
- The main **disadvantage** of the IORT is the dose delivery in a single session.

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