Special Treatment Techniques
Aims

To present an overview of the most common complex treatment techniques used for special situations
- In addition to conventional 2D/3D/IMRT external beam radiotherapy techniques, electrons and brachytherapy, special treatment techniques and clinical scenarios exist which may require additional hardware, labour and/or quality assurance. In many cases these are applied in larger radiotherapy centers.
Special Treatment Techniques

• Large field radiation
  – Total Body / Half Body
  – Total Lymphoid / Total Marrow
• Stereotactic
  – Radiosurgery / Radiotherapy
  – Body Radiotherapy
• Cranio-Spinal radiation
• Hypo/Hyper-fractionation
• Pediatric

Hypo and hyperfractionation regimes are dealt with in another lecture and will not be discussed here. Pediatric radiotherapy is a special subject by itself and is not covered in this course.
Special Treatment Techniques

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• **Cranio-Spinal radiation**

• **Hypo/Hyper-fractionation**

• **Pediatric**
Large Field Radiation (LFR)

• Specific learning objectives
  – Identify the clinical indications for LFR
  – Recognize the specific challenges of LFR
  – Compare the delivery techniques for LFR
  – Evaluate which techniques may be appropriate for one’s own clinical reality
We will first discuss total body irradiation

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Total body irradiation is often used in bone marrow transplants, both for adults and children, as part of the conditioning regime for transplant. This is true for autologous stem cell as well as allogeneic transplants.

The standard protocol uses high total radiation dose. This can be given as a single fraction or multiple fractions. Note that the single fraction regime exceed the Lethal Dose 50% (LD50) for man.

Reduced dose TBI gives a smaller dose of 2 – 4 Gy in a single fraction.
Stem cell, bone marrow transplant

- Types
  - Autologous (the patient’s own cells)
  - Allogeneic (from a related or unrelated donor)

- Goals
  - Kill cancer cells (malignancies)
  - Immune suppression (autologous transplants)

In autologous transplants, the patient’s own blood stem cells are harvested and expanded in the lab with aim to be given later.
The commonest indications for transplants are for haematological malignancies. In patients treated for leukemia/lymphoma, additional radiation if often delivered to so called “sanctuary sites” (typically testes in male acute lymphocytic leukemia patients) or sites of disease bulk (large lymph nodes in lymphoma patients)

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**Stem cell, bone marrow transplant**

- **Indications**
  - Malignancies
    - Leukemia (most common)
    - Multiple myeloma
    - Myelodysplasia
    - Lymphoma
    - Selected solid tumors
      - Neuroblastoma, Ewings,..
  - Non-malignant conditions
    - Aplastic anemia, severe combined immunodeficiency disorder
TBI is often fractionated with patients treated 2x per day, in the morning and evening. Fractionation reduces the risk of toxicity to OAR especially lungs.
Palliative / Immune-modulatory TBI

- Example Indications
  - Immune-modulatory
    - Anecdotal benefit in myastenia gravis
  - Palliative
    - Total doses of 150-200cGy result in a high response rate for chronic lymphocytic leukemia and indolent lymphomas

- TBI is used with decreasing frequency for these indications

Total body irradiation for myasthenia gravis: a long-term follow-up.

Review Article Low dose radiotherapy in indolent lymphomas, enough is enough
Issues and challenges of TBI

• Organizational
• Clinical
• Physical
  – Field size
  – Dose rate
  – Dose homogeneity
  – Tissue shielding / compensation
  – Commissioning
Long treatment times means that the machine is used for practically half the day for TBI. The scheduling of TBI must also be within the planned chemotherapy and transplant protocol. Teamwork is essential to ensure the smooth operation of TBI.
Clinical challenges of TBI

- Treatment techniques must consider
  - Children potentially under anesthesia
  - Potentially long treatment times in weakened patients

Limitations to standing / sitting techniques. Long treatment times for patients who are unwell is challenging as they are not comfortable and may move during therapy. Monitoring of general anesthesia from outside the room is also challenging.
Physical challenges of TBI

- Production of large fields with
  - Co$^{60}$
  - Megavoltage x-rays (linac-based techniques)
- Use of
  - Dedicated irradiators
  - Modified conventional megavoltage radiotherapy equipment

The maximum field size for EBRT is usually 30 cm (Cobalt) – 40cm (Linac). For TBI, field size of 200cm is often required needing extended SSD for treatment. This requires a large treatment room for TBI with one room wall about 4-5 meters from isocentre.
Physical challenges of TBI

- Typically parallel-opposed irradiation with 2 patient setups/positions
  - Occasional setups with more than one radiation source and a single patient position
- Beams
  - Stationary with field sizes of the order of 70x200 cm² encompassing the whole patient
  - Moving, with smaller field sizes, in a translational or rotational motion to cover the whole patient
Dedicated irradiators

- Treatment machines specially designed for total body irradiation.

Modified cobalt unit with modified collimation and filtering
Radiation Oncology Physics: A Handbook for Teachers and Students - 15.3.4 Slide 2
Dedicated irradiators

- Two linear accelerators mounted to produce two opposed beams
Set up varies between standing and lying positions. The most common position is with the patient lying on the side with the beam irradiating from anterior and posterior as to decrease the thickness of the treated fields. This would require 2 different patient positions for the treatment. This method also allows for lung shielding which is not established for lateral fields.
Can do “IMRT” by varying speed during translation
Translational couch TBI treatment setup.
Modified conventional

- Treatment with a swivelling or rotating beam

Varying SSD at feet vs. chest can compensate for variation in patient thickness, fewer and fewer devices in operation with the capability to swivel
Physical challenges: Dose Rate

- Toxicity, especially pneumonitis after single-fraction TBI, is related to dose and dose rate
- Depending on the clinical protocol, the dose rate may be specified in the range of 5 – 15cGy/min at the prescription point (typically the midpoint at the level of the umbilicus)
  - For extended SSD techniques, the lowered dose rate may be a natural result of distance
  - For Co\(^{60}\) based techniques with a shorter SSD, this may require special filtration
AAPM Report 17.

The prescription point of TBI is in the middle of the field typically at / near the umbilicus. The upper and lower prescribed dose is also used and tried to be kept to ± 5% but may not be possible practically. The maximum dose to critical organs should also be mentioned.

Due to changes in the separation/thickness of the patient, there will be considerable dose inhomogeneity. The use of compensators to thinner parts eg legs and ankles could improve dose homogeneity. Higher beam energy also decreases inhomogeneity between superficial and deep tissue but will spare skin and superficial structures eg skull. If these are in the target volume, then there will be underdosing of these areas.

Of particular importance is the correction for lung as it is a critical structure with low radiation dose tolerance and tends to receive higher dose due to increase transmission because of lower density. They can be shielded with various methods.
The graph shows that with increasing patient thickness there is increasing dose inhomogeneity which is improved with higher photon energies.
AAPM Report 17

In patients with organ dysfunction, it may be desirable to reduce the dose to those organs (lungs, kidneys, liver) through compensation/blocking which could be done after a certain dose to these organs. Frequent port films will be required to ensure the placement of the blocks.
Physical challenges: Commissioning

• The basic dosimetric parameters for TBI include:
  – Absolute beam calibration
  – Percentage depth doses or tissue-phantom ratios
  – Off-axis ratios

• These must be measured in the same conditions as will be used clinically
Physical challenges: Commissioning

• Of special concern are:
  – Large radiation fields and scattering from the treatment room floor or walls.
  – The size of the patient or calibration phantom smaller than radiation the field size.
  – The measured ionization chamber current may be of the order of the leakage current leading to errors in beam output determination.
  – A large portion of the ionization chamber cable may be irradiated with the large TBI field producing a significant non-dosimetric ionization chamber current.
Physical challenges: QA

- The quality assurance protocols fall into three categories:
  - Basic quality assurance
  - Pre-treatment quality assurance
    - calibration and preparation of equipment and the treatment room immediately preceding the TBI treatment
  - Treatment quality assurance
    - measurement of the dose delivered to the patient during the TBI procedure

From AAPM Report 17

It is desirable to have an in vivo measurement technique available. One method for finding midline doses employs entrance and exit thermoluminescent dosimeters (TLD’s). However, this approach must be used with care in order to obtain acceptable results. Measurements on a single patient could yield less accurate midline doses than those determined by calculation.

Systematic errors can result if the effects of lack of scatter on the exit surface are not considered. Averaging the appropriate data derived from a large number of patients can be useful. Entrance and exit dosimeters, for example, can be used to monitor the midline dose to the lung. By averaging over a number of patients and separating into broad ranges of patient size, correction factors can be generated for predicting the lung dose for any situation. However, this methodology should be carefully verified with phantom experiments.
What have we learned?

• What is a typical indication for TBI?
• What is a typical dose prescription for conditioning pre stem cell transplant?
• Where is it prescribed, at what dose rate and with what homogeneity?
• For my center and practice, what is a reasonable technique? Why?
Special Treatment Techniques

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  – Body Radiotherapy
• Cranio-Spinal radiation
• Hypo/Hyper-fractionation
• Pediatric
Half-Body Radiation

- **Rationale and indications**
  - Re-treatment is common after involved-field palliative radiation of bony metastases
  - Indicated in selected patients with diffuse symptomatic bony metastases

- **Falling out of favour because of..**
  - **Toxicity:** gastro-intestinal, hematological, ..
  - Better imaging to define symptomatic sites
  - Better systemic therapies available
The 3 halves

- Upper Hemi-body
  - Head to lower costal margin
  - Typically treated to a single fraction of 6Gy
  - Head can be excluded if uninvolved

- Lower Hemi-body
  - Lower costal margin to feet
  - Typically treated to a single fraction of 8Gy
  - Distal lower extremities can be excluded if uninvolved

- Middle Hemi-body
  - In between the upper and lower
  - Treated to a single fraction of 6-8Gy depending on the field borders

Note that for bone metastases it is possible to use non-tradiational “hemi-body” treatment; upper half from mastoid to iliac crest, lower half from iliac crest down and middle half from top of diaphragm to obturator foramen. The dose fractionation regimes are 8Gy in 2 fractions bid over 1 day, 12 Gy in 4 fractions bid over 2 days and 15Gy in 5 fractions daily for 5 days.

Salazar OM et al IJROBP Vol. 50 No.3 pp 765 2001
Hemi-body radiation is less labour intensive and easier to set up compared with TBI. In fractionated protocol of 15 Gy in 5 fractions or 12 Gy in 4 fractions bid, lung protection was required for the last fraction.
Non-isocentric (SSD) technique is needed as patient are treated with extended SSD.

Half-body vs. Total Body

• Similarities
  – Typically non-isocentric techniques
  – Although 2D or 3D planning can be used, half-body treatments can (as TBI) be planned clinically
  – Bolus can be used (typically in lower half-body treatments) to improve dose homogeneity
What have we learned?

• What is the typical indication for half-body radiation?
• What is a typical dose prescription for upper half-body radiation?
• On my own equipment, what is the maximum field size I could use for half-body radiation?
Special Treatment Techniques

- Large field radiation
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- Pediatric
- Cranio-Spinal radiation
Total Lymphoid Irradiation

- Rationale and indications
  - Radical or consolidative therapy of lymphoid malignancies
  - Immune modulation / suppression in varied benign and malignant conditions
    - Reduced-intensity transplants for lymphoid/myeloid malignancies
    - Immune modulation for solid organ transplant, autoimmune diseases
  
- Falling out of favour because of..
  - Trends for involved-field radiation in lymphoma
  - New pharmaceutical means of immune suppression

Due to improved chemotherapeutic and targeted therapies, TLI are not often used now. Treatment of lymphomas is now with chemotherapy with irradiation of involved lymph nodes only if necessary.
TLI – Time, Dose, Fractionation

• Variable and will depend on specific protocol used
  – Time: lymphoid malignancies will typically be treated daily, immune modulation has typically been delivered twice weekly
  – Dose
    • lymphoid malignancies: 20-40Gy total dose
    • immune modulation: typically 8Gy total dose
  – Fractionation
    • lymphoid malignancies: 1.5-1.8Gy per fraction
    • immune modulation: typically 0.8Gy per fraction
TLI – Target volumes

- Variable but typically central lymph nodes and spleen

- On standard isocentric linacs, this typically means 3 pairs of opposed portals
The mantle field will have the same homogeneity issues (compensation, forward IMRT) than in a typical Hodgkin’s lymphoma port.
It is possible to achieve TNI more easily with modern equipment such as tomotherapy.
What have we learned?

- What is the typical indication for total lymphoid radiation?
- Where in the body are the fields matched?
Special Treatment Techniques

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- Pediatric
- Cranio-Spinal radiation
Total Marrow Irradiation

- Meant to be less toxic than total body radiation when the target of interest is felt to be the bone marrow (e.g., multiple myeloma stem cell transplant conditioning)
- A complex technique that requires image-guided inverse-planned intensity-modulated radiotherapy, reliable immobilization, ...
- For now, an experimental treatment, best delivered as part of a formal clinical trial
It is possible to do Total Marrow irradiation with either tomotherapy or Linac based planning

Linac-Based Intensity Modulated Total Marrow Irradiation (IM-TMI) Bulent Aydogan, Ph.D.1,2,*
Arno J. Mundt, M.D.3 John C. Roeske, Ph.D.1,2 , Technology in Cancer Research and Treatment, Volume 5, Number 5, October (2006)


2006
With complex treatment planning, it is possible to treat the bone marrow while sparing normal tissues.
What have we learned?

• What is the rationale for total marrow irradiation?
• How many man hours of work do I estimate would be needed from immobilization to treatment?
• How would I deliver such a treatment without helical tomotherapy?
Special Treatment Techniques

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• Pediatric
Stereotactic Radiation

• Specific learning objectives
  – Give a definition of “stereotactic” and “radiosurgery”
  – Recognize the fading boundary between stereotactic radiation and high-technology conventional radiation treatments
Stereotactic

- Refers to a specific 3D coordinate system, traditionally fiducial-based

Stereotactic is not exclusive to radiotherapy. The earliest development of stereotactic equipment was for surgery (picture left). The “needle” was replacement with radiation beams for stereotactic radiotherapy.
Initial body stereotactic radiotherapy relied on analogous external fiducial systems (as the Elekta body frame or this Medical Intelligence BodyFIX system)
Any coordinate system could theoretically be used.
Radiosurgery

“the precise application of a single, high dose of radiation to a small (intracranial) target”

picture of radiosurgery with a 200kV x-ray tube

the definition of radiosurgery is clouded by political and financial issues (in the US, for reimbursement (and scope of practice) purposes stereotactic radiotherapy in 2-5 fractions is also radiosurgery)
In trying to intentionally treat lesion in normal tissue (trigeminal neuralgia 80Gy) it makes sense to use single fraction, in brain metastases is it probably just convenient in patients who often have short life expectancy but biologically inferior for fractionation to a higher total dose. With stereotactic therapy, more normal tissue outside the target volume can be spared. Single fraction therapy works best with smaller lesions < 3cm
In many benign, slow growing tumors, the benefit of fractionation is still debated/debatable (picture is juvenile pilocytic astrocytoma in young teenager (she subsequently had radiation necrosis).
patient treated at McGill over 2 weeks with halo, the point is that stereotactic radiotherapy used to be easily understood as meaning the application of the means of radiosurgery over multiple fractions
Now that the means of radiosurgery and “conventional” high-technology radiotherapy are often similar (or the same), it is less clear what stereotactic radiotherapy is. Typically stereotactic treatments refer to small targets addressed with very conformal plans delivered with, typically, non-coplanar beams.
Stereotactic Body Radiotherapy

Definition: "I know it when I see it"

<table>
<thead>
<tr>
<th></th>
<th>3D/IMRT</th>
<th>SBRT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dose/fraction</td>
<td>~1-8 Gy</td>
<td>~5-35 Gy</td>
</tr>
<tr>
<td># fractions</td>
<td>~1-44</td>
<td>~1-10</td>
</tr>
<tr>
<td>Dose homogeneity</td>
<td>moderate to high</td>
<td>low to moderate</td>
</tr>
<tr>
<td>Total biological dose</td>
<td>low to moderate</td>
<td>moderate to high</td>
</tr>
<tr>
<td>Target</td>
<td>well or poorly defined</td>
<td>well defined</td>
</tr>
<tr>
<td>GTV to PTV margins</td>
<td>larger</td>
<td>smaller</td>
</tr>
<tr>
<td>Accuracy</td>
<td>high</td>
<td>higher</td>
</tr>
<tr>
<td>Motion management</td>
<td>sometimes</td>
<td>always</td>
</tr>
<tr>
<td>Non-coplanar beams</td>
<td>rare</td>
<td>not rare</td>
</tr>
</tbody>
</table>

There is no single definition of SBRT. In general, SBRT uses fewer fractions with high doses per fraction of treatment.

The “I know it when I see it” phrase is credited to a supreme court judge Potter Stewart describing obscenity.
What have we learned?

• Give an example where single fraction high dose treatments are biologically sensible

• Give an example of a treatment that is clearly 3DCRT, one that is clearly SRT and one that may be at the interface of 3DCRT and SRT
Special Treatment Techniques

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• Hypo/Hyper-fractionation
• Pediatric
Stereotactic Radiosurgery/SRT

• Specific Objectives
  – Describe the history of radiosurgery
  – List some indications for radiosurgery
  – List basic physical and clinical requirements for radiosurgery
  – Describe type of radiosurgery devices
  – Contrast frame-based and frameless radiosurgery
  – Describe dose selection
Stereotactic Radiosurgery/SRT

• Specific Objectives (cont)
  – Explain how dose is prescribed
  – Explain dose evaluation tools
    • Conformality
    • Homogeneity
    • Gradient
  – List some additional steps in radiosurgery commissioning
  – List the 3 types of quality assurance protocols
History

- Combined use of stereotaxy and irradiation was introduced by Lars Leksell in 1951 in Stockholm, Sweden.
- Leksell coins the term “radiosurgery”
History

- Leksell starts radiosurgery with 200 kVp x-rays in the early 1950s
- In the late 1950s Leksell moves radiosurgery to proton and charged particle beams
- Leksell also designed and developed the first Gamma Knife installed in 1968
- Megavoltage x-ray beams from isocentric linacs used in radiosurgery starting in 1980s
- Dedicated, frameless and non-isocentric robotic linac radiosurgery, 1990s

Leksell moved to cobalt sources due to limitation with other forms of radiation sources. The first Linac based stereotactic radiosurgery was performed in 1982 in Paris.
Indications

- The diseases treated with stereotactic irradiation fall into one of five categories:
  - **Functional disorders:**
    - trigeminal neuralgia, Parkinson’s disease, epilepsy, ...
  - **Vascular lesions:**
    - arteriovenous malformation (AVM), cavernous angioma, ...
  - **Primary benign tumours:**
    - pituitary adenoma, acoustic neuroma, meningioma, ...
  - **Primary malignant tumours:**
    - glioblastoma multiforme (GBM), medulloblastoma, ...
  - **Metastatic tumours**
Physical Requirements

- Accurate determination of the target volume and its location (if necessary, 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
- Dose distributions that conform to target shape and give a **sharp dose fall-off** outside the target volume
- Direct superimposition of isodose distributions on diagnostic images, showing the anatomical location of the target
Clinical Requirements

- Accurate knowledge of the total dose and fractionation scheme required for treatment of a particular disease.
- Accurate positional (within +/- 1mm) delivery of dose to the pre-determined target.
- Accurate numerical (within +/- 5%) delivery of dose to the pre-determined target.
- Low skin dose and low lens dose
- Low or negligible scatter and leakage dose
Type of photon radiosurgery planning

- Single sphere, sphere packing
- MLC fields
  - fixed
  - arcs, dynamically shaped arcs
  - fixed-field IMRT, volumetric IMRT
- Tomotherapy (serial, helical)
- Non-isocentric “dose-painting” with circular fields

Sphere packing is a Multiple Isocenter Method' which involves filling the tumour image with spheres of different sizes, until the image is best filled-up.

A TREE IN A BRAIN TUMOR
TAEIL YI, maa.org/florida/proceedings/2001/yi.PDF

In volumetric IMRT, the gantry speed and dose rate vary continuously during delivery for a 178 degree arc. In addition, there is full leaf interdigitation, allowing multiple small islands of dose to be delivered to the planning target volume (PTV) at each gantry position. This compares with fixed field IMRT where usually 5-7 treatment positions are used.

Volumetric Intensity-modulated Arc Therapy Vs. Conventional Imrt In Head-and-neck Cancer: A Comparative Planning And Dosimetric Study
WILKO F. A. R. VERBAKEL
Type of photon radiosurgery planning

Circular Arc  Sphere Packing  Conformal Shaped Beams  Dynamic Shaped Arcs

Intensity Modulated SRS/SRT  Volumetric Intensity Modulated Arcs  Tomotherapy  Non-isocentric dose painting
How to get non-coplanar x-ray fields

• Move the patient
• Move the machine
• Move patient and machine
  – One at a time
  – At the same time
Gamma Knife® radiosurgery - principles

- Protective shielding
- Collimator channels
- Leksell® Coordinate Frame
- Isocenter/
  Target in the brain
- Patient positioning system
- Radiation sources
There are many different frames available but essentially they are either invasive frame or relocatable frames. The invasive frame as it name suggest, need to be literally screwed onto the patient. The relocatable frame is applied rigidly to the patient but does not require invasive procedure. These frames usually have a maximum isocentre displacement of 2mm.
Many different forms of machines are capable of stereotactic treatment. The main ones are: gamma-knife, Linac-based or x-knife and cyberknife.

Gamma knife uses multiple cobalt sources for stereotactic therapy while the Linac uses specialised collimators for stereotaxis with a fixed isocentre. The Cyberknife a special small linac unit mounted on a robotic arm enabling a non-isocentric treatment.

cobalt units, modified or dedicated isocentric linacs (may want to mention that floor stands are now unnecessary/out of fashion, dedicated non-isocentric linac
Modified Isocentric Linacs

- The most important requirement of a linac used for radiosurgery is the stability and accuracy of its isocentre.
  - Under ideal conditions, the isocentre is defined by the fixed point of intersection of the gantry rotation axis and the treatment couch or chair rotation axis.
  - In reality, the isocentre is the middle of a best compromise sphere — for radiosurgery, this sphere should have a diameter of no more than 1mm.

- Additional mechanical modifications needed can be relatively simple
  - Supplementary collimation
    - Either in the form of a set of collimators to define small conical beams
    - Or a miniature MLC to define small area irregular fields
  - Table brackets for immobilizing the stereotactic frame during treatment.
  - Special brakes to immobilize the vertical, longitudinal and lateral table motions during treatment.
  - Image-guidance (optional)
Dose Selection

• The prescribed dose and dose fractionation in stereotactic dose delivery depend upon
  – Volume (or diameter) of the intracranial target
    • The maximum tolerated dose decreases with increasing size
    • Single fraction dose to target >4cm in diameter is typically either ineffective or unsafe
  – Location of the intracranial target
  – The type of disease treated
  – Equipment and technique
  – Prior Treatment

Typical doses for brain metastases (taking into account prior whole-brain radiation) are:
• 20-24Gy/1 for lesions <2 cm,
• 18Gy/1 for lesions 2-3 cm and
• 15Gy/1 for lesions 3-4 cm.

• The dose limiting toxicity is generally radiation necrosis. Benign tumours may be prescribed lower doses (for example – 12-13Gy/1 for acoustic neuromas).
Dose Prescription

- Radiosurgery dose is prescribed as the minimum dose covering the target
  - This is often loosely interpreted as covering 98-99%
- SRT prescriptions are sometimes reported this way, sometimes as per ICRU 50, 62, 83

20Gy to isodose covering 99% of target
Dose Evaluation

• Visual inspection and DVH still important but additional factors of:
  – Conformity
  – Homogeneity
  – Gradient

• Each of these factors has indices
  – Conformality indices (ex. PITV, nCI)
  – Homogeneity indices (ex. MDPD)
  – Gradient indices (ex. GI)
Dose Evaluation: Homogeneity

- In “standard” radiotherapy, homogeneity +7%/-5% is important
- In radiosurgery, where little or no normal tissue is within the target, conformality is often preferred over homogeneity and plans can be very inhomogeneous
Dose Evaluation: Homogeneity

- Dose is typically specified to a percentage of the maximum dose within the patient (hopefully within the target) – example 20Gy to the 80% isodose surface
  - Should typically be 50-100% isodose
- MDPD index is max dose/prescription dose

\[
\text{MDPD} = \frac{100}{50} = 2.0
\]
Plan Evaluation: Conformality

- PITV index is the volume within prescription isodose volume divided by the target volume
  - Ideal is 1 (less than prescribed dose to all non-target tissue)
  - Typically should be <2
  - Does not account for untreated target (nCI)
  - Does not reflect absolute volume

\[ \text{PITV} = \frac{\text{Volume of prescription isodose}}{\text{Volume of target}} \]

The nCI is the volume of prescription isodose / volume of target within isodose volume (in most cases it is similar or identical as PITV)
Plan Evaluation: Gradient

- (Paddick) Gradient index (GI) is the isodose volume at half the prescribed dose / prescription isodose volume
  - Ideal is 1 (impossible), lower is better
  - Variable but in the range of 2-3

10 Gy isodose volume = 1.2 cc

Prescription (20Gy) isodose volume = 0.6 cc

GI = 1.2 / 0.6 = 2
Commissioning

- The basic principles in commissioning of radiosurgical devices are similar to those used for commissioning of standard radiotherapy equipment, with more stringent requirements for machine integrity and performance.
- The procedures for commissioning of all radiosurgical devices can be similar, despite large variations in dose delivery techniques.
Commissioning

• The following issues should be considered before clinical use of a radiosurgery device:
  – The properties of radiation beams must be measured to ensure patient safety and accurate treatment planning.
  – The mechanical integrity of the radiosurgical device must be within acceptable tolerances.
  – All steps involved in the radiosurgical procedure, from the target localization, through treatment planning, to dose delivery, must be verified experimentally.
Quality Assurance

• Three categories of protocols:
  – Basic quality assurance protocols covering:
    • Target localization
    • 3-D treatment planning
    • Radiosurgical delivery of dose
  – Treatment quality assurance protocols dealing with the calibration and preparation of equipment immediately preceding the radiosurgical treatment.
  – Treatment quality assurance protocol during the radiosurgical procedure on a patient.
Case example: AVM

- Install frame
- Image
  - DSA with external DSA fiducials
  - CT-A with external CT fiducials
- Localise
- Contour
- Plan
- Prescribe
- QA Plan, QA Machine
- Deliver radiation
- Remove frame
DSA gold standard as the only test that has the time component, still no obvious way to incorporate into frameless radiosurgery (a spin can be made, converted into a cone beam CT and fused to the planning CT)
The 2 squares are the fiducials to translate what is seen into a 3D coordinate system, the dots are part of a grid used for distortion correction.
CT-angiogram, CT localizer rods are visible on 3 sides or the localizer box, DSA localizer squares (seen in prior slide) can be seen on all 4 sides
The target is then localised and contoured on the DSA images.
The volume is transferred to the CT-simulation images. A radiation plan is made.
The coverage of the CTV is evaluated and dose prescribe. Dose prescription is not to the isocentre but to the minimum isodose covering the target volume. This is typically 80% isodose but other levels can be chosen.
There is typically a checklist QA of all of the steps in the treatment of the patient, a second check of the dose calculation, Winston Lutz, in addition to all of the non-patient-specific QA that goes into radiosurgery.
What have we learned?

- What are the different types of radiosurgery devices?
- What are the types of radiosurgery planning available to each device?
- What is the meaning of a PITV of 1.5?  
  - How can this be misleading?
- What would the day’s activities be for a frame-based treatment of a single metastasis (best seen on MRI) on a linac with conical collimators?
Special Treatment Techniques

- Large field radiation
  - Total Body / Half Body
  - Total Lymphoid / Total Marrow
- Stereotactic
  - Radiosurgery / Radiotherapy
  - Body Radiotherapy
- Hypo/Hyper-fractionation
- Pediatric
- Cranio-Spinal radiation
Rationale for SBRT

- Means to deliver highly potent radiotherapy in short time period, avoiding re-population (60/3 may be equivalent to 20 weeks of conventional radiotherapy)
  - May have unique (?vascular) biological effect
- Used for well-defined targets in paradigms similar to surgery
- Convenient and possibly cost-effective
  - Allows more complex treatments which would be inconvenient to deliver on a daily basis
- Normal tissues spared by use of small margins and highly conformal plans
History of SBRT

- Follows history and success of intracranial SRS
- Initial “frame-based”
- First publications in 1990s
- First well-known prospective trials in lung
- Indications expanding to a wide variety of clinical sites

Stereotactic Body Radiation Therapy for Inoperable Early Stage Lung Cancer
Robert Timmerman et al
JAMA, March 17, 2010—Vol 303, No. 11 (Reprinted)
Indications for SBRT

• Mature
  – Medically inoperable T1-T2 primary NSCLC

• Maturing
  – Liver (HCC, oligometastases, cholangiocarcinoma)
  – Spine (oligometastases, retreatment)

• Immature
  – Prostate
  – Pancreas
  – Adrenal
  – …
SBRT is defined by the product, not the tools

- What tools are needed for SBRT?
  - Immobilization
  - Motion management
    - 4DCT
    - Gating
    - Tracking
  - IMRT
  - Image-guidance
Not every case needs same tools
Not every department uses same tools

- Lung
  - Motion management / 4DCT
- Liver
  - Motion management / Gating
- Spine
  - Immobilization
  - IMRT
  - Image-guidance
Issues in plan evaluation, dose prescription for SBRT

• Plan evaluation
  – Need to re-learn dose tolerances for hypofractionated courses
• Published dose prescriptions are variably defined
  – isocenter vs. volume
• Treatments may be better tolerated when delivered every other day
  – consequential toxicity, ...

For the last point can quote Stanford experience with prostate (5 fractions) where the QOD treatment had much less GU and GI toxicity than the QD regimen
Note the use of absolute volume. The tolerances of organs is different from traditional tolerances with conventional radiotherapy. Here point doses and volume of the organ becomes critical.

### Examples of normal tissue tolerances

#### Liver tolerance, AAPM TG101

<table>
<thead>
<tr>
<th>Volume</th>
<th>1 Fraction</th>
<th>3 Fractions</th>
<th>5 Fractions</th>
</tr>
</thead>
<tbody>
<tr>
<td>&gt; 700cc below threshold</td>
<td>9.1Gy</td>
<td>19.2Gy</td>
<td>21Gy</td>
</tr>
</tbody>
</table>

#### Colon tolerance, AAPM TG101

<table>
<thead>
<tr>
<th>Point dose</th>
<th>1 Fraction</th>
<th>3 Fractions</th>
<th>5 Fractions</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 20 cc</td>
<td>18.4Gy</td>
<td>28.2Gy</td>
<td>38Gy</td>
</tr>
<tr>
<td></td>
<td>14.3Gy</td>
<td>28.2Gy</td>
<td>25Gy</td>
</tr>
</tbody>
</table>

#### Stomach tolerance, AAPM TG101

<table>
<thead>
<tr>
<th>Point dose</th>
<th>1 Fraction</th>
<th>3 Fractions</th>
<th>5 Fractions</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 10 cc</td>
<td>12.4Gy</td>
<td>22.2Gy</td>
<td>32Gy</td>
</tr>
<tr>
<td></td>
<td>11.2Gy</td>
<td>16.5Gy</td>
<td>18Gy</td>
</tr>
</tbody>
</table>
Dose Prescription
What can 45Gy/3 mean?

PTV covered by 67% isodose line (30Gy)
CTV covered by 95% isodose line (42.75Gy)

From liver SBRT experience of Hoyer et al.

This is not meant to be a guide as there are different interpretations
This is not meant to be a guide as there are different interpretations
This is an example of SBRT for an inoperable centrally located but small lung lesion.
The planning process is similar to other stereotactic treatment.
What have we learned?

- What is a mature indication for SBRT?
- How would I go about delivering 48Gy in 4 fractions to a lung tumor at my centre?
- What would I estimate the TD5/5 for the spinal cord to be in 3 fractions?
Special Treatment Techniques

• Large field radiation
  – Total Body / Half Body
  – Total Lymphoid / Total Marrow

• Stereotactic
  – Radiosurgery / Radiotherapy
  – Body Radiotherapy

• Cranio-Spinal radiation

• Hypo/Hyper-fractionation

• Pediatric
Cranio-spinal radiation (CSI)

- Specific learning objectives
  - Define the target volume for CSI
  - Understand the general indications for CSI
  - Understand the challenges in planning CSI
  - Compare treatment techniques for CSI
  - Make an argument for selecting a specific CSI technique
Cranio-spinal radiation target

- The space where CSF circulates

This is meant to illustrate the cribriform plate on left (one can mention that this is less likely to be missed with 3D planning than 2D), the thecal sac (where a limit can be set based on populational averages or, better, on a patient-specific MRI) and the optic nerves (although there is CSF, it is not clear, at least in medulloblastoma, if they need to be specifically targeted – this is only really an issue for IMRT as there are included in lateral portals aiming to cover the cribriform plate)
Cranio-spinal radiation indications

• Tumors which have a high risk of spread in the CSF or which have already seeded the CSF space
  – High propensity for spread
    • Medulloblastoma, pineoblastoma, PNET
    • CNS germ cell tumors
    • Acute lymphoblastic leukaemias
  – Have already spread
    • Ependymoma (high grade)
    • ...

2D vs. 3D

• Craniospinal irradiation can be done using 2D or 3D

• Advantages of 3D
  – Better visualization of the target
  – Better tools for dose homogeneity
  – IMRT possible
  – Complex treatment can be planned without keeping patient in simulator
  – Obviates the need for manual gap/angle calculations
  – Dose to normal tissue can be quantified
There are many challenges and issues in cranio-spinal irradiation.

In small children, a single posterior photon field is adequate to treat from cervical spine (usually C2) to S3/4 covering all of the thecal sac. For older children and adults, 2 posterior field are required. This brings about the problem of matching 2 diverging photon field. Various methods of matching have been used, typically at a calculated depth which creates hot and cold spots. Hot spot on the spinal cord is dangerous and risks cord necrosis. To overcome this problem, moving junction technique is used to “feather” the hot and cold spots.
The second issue of matching is with the cranial and upper spinal field. The posterior field has a sup-inferior divergence while the lateral cranial field have lateral divergence. Again this creates a hot-spot over the match line with potential risk of overdose at the spinal cord.
Solution A
To correct divergence, the required collimator rotation for the cranium field can be calculated from angle $x$ derived as arctan of $\frac{z}{y}$ field / SSD.

$$\text{angle } x = \arctan \left( \frac{z}{y} \right)$$

$$11.3^\circ = \arctan \left( \frac{20}{100} \right)$$
The second correction is for the divergence of the cranial field which can be achieved by a table rotation to “straighten” the divergence of the lower border.
The end effect would be a straightening of the lower cranial field
The second correction is for the divergence of the cranial field which can be achieved by a table rotation to “straighten” the divergence of the lower border.
The second solution is to treat the patient in a supine position and correct for all divergence by gantry, collimator and couch rotations.

The matching of the posterior spinal fields with 2 non-divergent beams is also possible as indicated by the diagram. In this technique the gantry is turned to correct divergence from the posterior fields. The calculation for the angle of rotation is the similar to that of the cranial fields.

Although in theory, the junction does not need to be moved, it is more prudent to move all junctions every 5-7 fraction as the matching is not going to be perfect.
Solution B

SPINE FIELD

Y1 = INF limit
Y2 = 10 cm

Y1 = INF limit
Y2 = 20 cm

or Y1 = 20 cm

BRAIN FIELD

10 cm

20 cm

BRAIN ISO

Y1 = 0 cm

Y2 = 20 cm

Collimator always 11 degrees
Solution B
With MLC, it is possible to compensate for areas of under-dosing using a field-in-field technique. In this method, smaller fields are used to treat underdose areas with successive field size reduction.
IMRT technique can also be used to compensate to areas of over- and under dosage.
The University of McGill uses a technique of asymmetrical jaws with fixed isocenter positions relative to the cranial fields.

Solution B

• Advantages
  – Supine position allows better access for anaesthesia
  – Supine position may be more stable
  – Supine position less sensitive to breathing
  – No height, lateral, or rotational couch movements between fields — only translations
  – No calculations
    • collimator angle always 11°
    • isocenters always at same distance (20cm and 30cm)

• Disadvantages
  – Requires asymmetric jaws
  – Uses additional anterior setup fields to visualise gap
Solutions A & B

• For all multi-field solutions, inhomogeneity at the field junctions is minimized by moving the junction
  – Typically by 1cm per 9Gy
  – Most easily done with asymmetric jaws (the impact on divergence is small enough to be ignored)
Junction planning

11°

20 cm  30 cm

22 cm  36 cm  12 + x cm
Tomotherapy is able to treat the whole CSI volume without any junctions.

It can start sparing some normal organs in the CSI (such as inner ears), a bit more dose to the anterior face.
Helical tomotherapy

- increased conformity and dose homogeneity
- no junctions
- lower maximum body dose (38 Gy vs. 48 Gy)
- less dose to anterior structures
- smaller PTV when low dose daily MVCT is used for IGRT

There is increased sparing of normal tissue especially avoiding high exit dose anterior to the vertebral column. The lack of junction minimises risk of over-exposure to the spinal cord.
Tomotherapy can achieve more uniform dose throughout the CSI avoiding areas of under-dose (A) and over-dose (B)

Lower curves are total body
What have we learned?

• For a multi-field technique with moving junctions, would you close the cranial field each 9Gy or open it? Why?
Summary

- There are several specialised radiotherapy techniques available for special clinical scenarios.
- Total body irradiation remain an important treatment modality in bone marrow transplants.
- Stereotactic treatment is well established for intracranial lesion and is being extensively studies for other parts of the body.
- Cranio-spinal treatment is especially important for certain childhood cancer.
- The sophistication of these specialised treatment requires more intensive planning and quality assurance with more manpower requirements.
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