Gamma Knife Radiosurgery

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Outline

- Basic Radiobiology
  - Foundations of Radiotherapy

- Treatment Technology
  - Linear Accelerator
  - Gamma Knife

- Indications for Gamma Knife

- Immobilization, Localization and Treatment Planning

- Conclusion
Basic Radiobiology

- Cancer arises from cellular mutations
  - Healthy cells ‘sense’ mutations and generally commit suicide
    - e.g. apoptosis, senescence
  - Cancerous cells bypass these mechanisms and are characterized by uncontrolled growth
- Radiation therapy generally delivered in small doses over many days (fractionation)
  - Due to their mutations, cancerous cells don’t repair themselves properly to fix the DNA damage
    - This in turn forces apoptosis / senescence
  - Healthy cells have a much better chance of repair
Basic Radiobiology

- Stereotactic Radiosurgery (SRS)
  - Single large dose delivered to target
  - Mechanism of fractionation no longer applies
    - ‘Ablative’ dose doesn’t allow for any repair (tumor or healthy tissue)
  - SRS relies heavily on highly accurate targeting
    - Deliver ablative dose to target, but only small doses to healthy tissue
Radiotherapy Delivery Mechanisms

- **External**
  - **Photons**
    - x-ray & gamma ray
  - Electrons
  - Protons
  - Heavy ions (C-16)

- **Internal (Brachytherapy)**
  - Photons
    - x-ray & gamma ray

- **Ingested**
  - electrons
    - beta ray (I-131)
Radiation Dose Delivered by Photons

- **Radiation Dose**
  - \[ D = \frac{E}{m} \text{ (J/kg or Gy)} \]

- **Dose deposition is a two step process**
  1. Photons transfer energy to electrons in the form of kinetic energy
    - Compton scattering
      - Photon interacts with loosely bound electron
    - Photo electric effect
      - Photon interacts with a tightly bound electron
    - Pair Production
      - Photon interacts with nucleus
  2. Electrons transfer kinetic energy to tissues
    - Elastic and inelastic scattering
Radiation Dose Delivered by Photon
Linear Accelerators (linacs)

- Electric source of x-rays
  - Linear Accelerator (linac)
    - Workhorse of RT department
    - Treat anywhere in the body
  - X-ray generation is a 3 step process
    1. Free electrons generated at electron gun
    2. High power microwaves accelerate electrons
    3. Electron kinetic energy converted to x-rays
Linacs

- Electrons injected into accelerating waveguide
  - Thermionic emission
Linacs

- High power radiofrequency electromagnetic waves transfer energy to electrons
  - electrons attain speeds of \( \sim 0.999c \)
Linacs

- The kinetic energy of the electrons are converted to x-rays as they interact with the nuclei of a tungsten target
  - Bremsstrahlung radiation (‘Braking radiation’)
Linacs

- Radiation Fields shaped with ‘Multi Leaf Collimator’
  - Conform to target shape
Gamma Knife

- 192 60-Co source arranged in ‘hemisphere’ to treat intracranial lesions only
Gamma Knife

- 8 independent sectors 3 collimator options
- Each with 4mm, 8mm, 16mm collimator options
Gamma Knife

- Radioactive source for gamma rays
  - 60-Co

\[
{^{60}_{27}}\text{Co} \\
5.272 \text{ a} \\
0.31 \text{ MeV } \beta^- \quad 99.88\% \\
1.48 \text{ MeV } \beta^- \\
1.1732 \text{ MeV } \gamma \\
1.3325 \text{ MeV } \gamma \\
{^{60}_{28}}\text{Ni}
\]

- Half life = 5.26 years
Gamma Knife - Indications

- Malignant tumors
  - primary brain tumors
  - brain metastasis – most common intracranial malignancy
    - Single or multiple mets
  - Doses vary based on tumor size (generally 15 – 24 Gy)\(^1\)

\(^1\) RTOG 9508: A phase III trial comparing whole brain irradiation with versus without SRS boost for patients with 1-3 brain metastasis
Gamma Knife - Indications

- Benign lesions
  - Trigeminal Neuralgia
    - Chronic pain that affects the trigeminal nerve (nerve which carries sensations from face to brain)
    - Even minor stimulation of the face can cause excruciating pain
    - Typical dose > 85 Gy
Gamma Knife - Indications

- Benign lesions
  - Acoustic Neuroma (Vestibular Schwannoma)
    - Benign lesion that develops on main nerve leading to inner ear
    - Can cause hearing loss, ringing in ear, and unsteadiness
    - Typical dose of 12 – 13 Gy
Gamma Knife - Indications

- Benign lesions
  - Arteriovenous Malformation (AVM)
    - Tangle of abnormal blood vessels connecting arteries and veins in the brain
    - Sometimes can cause headache or seizures
    - *Potential* to cause brain damage or stroke if left untreated
    - Typical dose of 16 – 20 Gy (depending on size)
Gamma Knife - Indications

- Functional disorders
  - Epilepsy
    - Medial Temporal Sclerosis (associated with Medial Temporal Lobe Epilepsy) shows radiographic changes on MRI
    - Epilepsy leads to seizures
    - Dose of 20 – 29 Gy
  - Tremors (e.g. Parkinson’s Disease)
    - Also known as Gamma Knife Thalamotomy
    - Targets the thalamus
    - Dose of 130 – 140 Gy
Gamma Knife – Practical Considerations

- Gamma Knife unit is a classified as a class I radioactive source
- Has implications for licensing by the Canadian Nuclear Safety Commission (CNSC)
- Gamma Knife vault designed to minimize radiation exposure to nuclear energy workers and the general public
- Unit weights 22 tons
- 60-Co generated in nuclear reactor
- Radioactive sources exchanged every 5 years
  - Approximately every half life
Gamma Knife – Imaging

- Patient imaging
  - Magnetic resonance imaging (MRI)
  - Computed Tomography (CT)
  - Angiography (arteriovenous malformations)

- In order to treat accurately, the patient imaging space (e.g. MRI) and the gamma knife treatment unit must be aligned
  - Frame based
  - Frameless
Gamma Knife - Immobilization

- Currently 2 immobilization techniques
  - Due to highly precise delivery, patients are immobilized to prevent treatment errors
    - Frame based:
    - Frameless:
Gamma Knife - Immobilization

- Frame based
  - Bolted into skull by neurosurgeon or trained radiation oncologist
  - ‘Gold standard’ SRS technique
Gamma Knife – Localization

- Frame based localization
  - Localizer boxes attached to frame
  - Frame attached to Gamma Knife machine
Gamma Knife – Localization

- Frame based localization
Gamma Knife – Framed Based Workflow

General Treatment Workflow

On Day of Treatment:

- Patient arrives early and NS or RO attaches frame
- Patient receives imaging
  - Proposed Imaging
    - Brain Mets: MRI only
    - High Dose Treatments (e.g. TN, Tremor, near eloquent areas): MRI + CT
    - AVM: MRI + Angio
- Treatment plan created (location and size of ‘isocenters’)
- Patient receives treatment
  - 15 min – 1.5 hrs (or longer depending on disease)
  - Note: treatment times increase as the 60-Co sources get older (replaced every 5 years)
Gamma Knife – Immobilization

- Elekta’s latest technology allowing for Frameless Stereotactic Radiosurgery (ICON)
- Thermoplastic Mask restricts motion
- Patient is observed during treatment via infrared imaging \((\text{real-time motion management})\)
Gamma Knife – Localization

- Cone Beam CT taken at time of treatment registered to previous MRI scan

https://www.youtube.com/watch?v=ITjJgpXSnd4
Gamma Knife – Frameless Workflow

- **ICON Treatment Workflow**
  - **Prior to Treatment Day**
    - Patient to receive MRI with no frame
      - Treatment plan can be created on MRI
    - Patient thermoplastic mask is created
  - **On Day of Treatment:**
    - Patient receives Cone Beam CT (CBCT) on ICON
    - MRI and CBCT images are registered and fused
      - Treatment plan created (if not done before)
    - Patient receives treatment
      - 15 min – 1.5 hrs (or longer depending on disease)
Gamma Knife – Frameless Workflow

- Potential Benefits of the ICON
  - No frame – therefore becomes a truly non-invasive treatment option
    - All patients don’t have to show up first thing in the morning
  - Potentially better workflow for patients if treatment planning is done prior to treatment day
    - Patient doesn’t have to wait for treatment plan to be created

- However...
  - Not appropriate for tumors near eloquent areas
  - CBCT quality worse than diagnostic CT
  - Registration of CBCT with MRI needs evaluation on a per patient basis
Gamma Knife – Treatment Planning

- Dose accumulated in target by using multiple ‘isocenters’
  - Gamma Knife dose focused to a small sphere
  - Move patient to change where the focal point is located
Gamma Knife – Treatment Planning
Conclusion

- Gamma Knife is an exciting technology that will allow for a wider array of indications to be treated in Edmonton

- Tested and Proven technology

- Potential for cutting edge clinical research