Advanced Technologies – GammaKnife/CyberKnife/Tomotherapy

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Objectives

- Introduce the modern and specialized non-C arm Treatment Devices
- Introduce operational principles and functions of each modality
- Quality Assurance (QA) of each treatment delivery device and demonstrate associated clinical applications
The patient lies on the table with the head frame locked into the collimator helmet and the patient is advanced into the lead shielded unit that contains the 201 radiation sources. The Gamma Knife can only treat tumors in the brain and skull base (Perfexion model can extend to the C spine region). First built in 1967 and treated in Stockholm, Sweden.
Advanced Gamma Knife Models

 Gamma Knife 4C  
 Starting 2004

 Gamma Knife Perfexion  
 Starting 2006
GK Treatment Clinical Process

Placing head frame

Using attached fiducial box with the stereotactic headframe for MR and/or CT imaging localization
After planning and data transfer, the headframe is affixed to the automatic positioning system (APS) and the door of the treatment unit will be opened and the patient is advanced into the shielded vault. Treatment is dose rate dependent.
- 201 Co-60 sources are focused so that they intersect at a single location.
- An elliptical region of high dose is produced with a rapid falloff in dose outside the boundary of the ellipse.
- Four focusing helmets are available (4 mm, 8 mm, 14 mm, 18 mm).
- Brain mets with 11 shots (only using 18 mm collimator)
- Isodose coverage by placing various “shots”
- Multiple (5) shots to conform irregular shaped targets
Dynamic Dose Shaping of Perfexion

Collimator system 16-16-16-16-16-16-16-16

Collimator system 8-16-8-16-8-16-8-16

Single Shot Dynamic Dose Shaping

Courtesy of David Larson
QA Requirements

Gamma Knife Routine QA Procedures

**Daily QA**
- Warmup
- Door interlock
- Emergency off
- AV communications
- Radiation monitor

**Weekly QA**
- Couch release handle
- Helmet microswitches
- Helmet trunions
- Automatic positioning system

**Monthly QA**
- Radiation output
- Computer output vs. measured
- Emergency rod release
- Medical UPS battery check
- Timer constancy, linearity, and accuracy

**Annual QA**
- Relative helmet factors
- Isocenter coincidence
- Film measurements
Cyberknife Basic Principles

- A treatment unit designed for both intracranial and extracranial radiosurgery.
- CyberKnife uses a compact linear accelerator mounted on a robotic arm, which has 6-degrees of freedom.
- Pencil beams of radiation are delivered sequentially as the robot moves around patient.
- The CyberKnife delivers frameless radiosurgery. During delivery, the patient position is monitored and the delivery is modified to correct for patient movement.
- kV images are obtained before and during the treatment to monitor the alignment of the patient.
Cyberknife – 2D Orthogonal Imaging for Positioning Correlation

Pair of x-ray images to match with DRRs from plan

2D matching, bony anatomy only, with soft tissue visibility
Cyberknife Treatment Candidates

- **Intracranial lesions**
  - ✓ Immobilization with regular aquaplast mask
  - ✓ Patient can be positioning and monitored using bony landmarks

- **Extracranial lesions**
  - ✓ Immobilization with vacuum bag (or Alpha Cradle)
  - ✓ Patient positioning is traced using either
    - Implanted fiducial markers (metal)
    - Spine tracking (Xsight spine module)
    - Synchrony lung tracking (motion tracking)
    - Soft tissue lung tracking (Xsight lung module)
6 MV X-band accelerator with 12 interchangeable circular collimators.
- At an SSD of 80 cm, collimators provide a beam diameter from 5 to 60 mm
- SSD can be varied from 65 to 100 cm
- Radiation is delivered at a discrete set of LINAC positions (called nodes).
- A typical treatment plan will use 110 nodes distributed approximately uniformly over about one half of a sphere centered on the treatment site. (no posterior beams)
Beam Orientations and Path Planning (Collision Avoidance)

Constraints:
- Avoid obstacles within the workspace
- Avoid obstructing X-ray cameras

Principle:
- Define a fixed dense grid of feasible source points on a sphere and a standard path through those points
- For each target point on the tumor, select beam orientation by picking a source point at random
Clinically Treatment and Image Tracking

Image guidance can be sub-divided into surface (skull) and fiducial maker tracking for positional correction.

Courtesy of David Shepard, Swedish Hospital
2 overlaid banks of 6 tungsten segments creates a 12-sided variable aperture combination

- Variable aperture automatically (conformal)

Replicate and replace sizes of the existing fixed 12 fixed collimators (5 to 60 mm)

- All segment are driven by a single motor for automation
QA Schedule of Cyberknife

DAILY
1. System Status Check
2. Linac Output Constancy Check
3. Safety Interlock Check

MONTHLY
1. Beam Parameters
2. Robot Mastering Check (Visual)
3. Imaging Targeting Check
4. Imaging Alignment (Image Isopost with Treatment Software)
5. Beam Energy (TPR 20/10 or PDD 20/10)
6. Film Phantom Target Test (or 2 Month Interval)

QUARTERLY
1. Target Locating System Tracking Test (or After Significant Change Due to Maintenance work)
2. Linac Laser Mechanical alignment check
3. Linac Laser/Radiation Field alignment check

ANNUALLY
1. Beam Commissioning Spot Checks
2. Treatment Planning System Tests
3. Beam Calibration Check
4. Safety Systems Tests
5. Robot Mastering (Electronic)
6. Couch Indexing Accuracy
Daily Output Check

- In air measurements are performed with attachment
- Ion Chamber output checks with temp and pressure correction
Anthropomorphic phantom for Cyberknife

- Cranial fiducial measurements using 2.5” Ball Cube for fiducial marking and skull tracking QA

- Film cassette enables accurate measurements with two orthogonal films. Can be used for QA the extracranial treatments.

Courtesy of Accuray, Inc
TomoTherapy Major Components

- Gun Board
- Linac
- Control Computer
- Circulator
- Magnetron
- Pulse Forming Network and Modulator
- High Voltage Power Supply
- Beam Stop
- Fan Beam CT Detector

TomoTherapy unit at MMC
The TomoTherapy Hi-Art System is completely air cooled so there is no need for a Chilled Water Supply.
Geometrical Accuracy

Mechanical Accuracy:
1. Radiation isocenter (Delivery and Imaging):
   - accuracy: 0.1 mm
2. Couch positioning (High Performance Couch):
   - accuracy: 0.1 mm
Dose Map from the Typical 81 Gy Prostate Tomo Plan

Treating lymph nodes and sparing the bladder and rectum

Treating prostate and sparing the rectum

51 beam entries and complex intensity modulation deliver great degree of freedom and sharper dose gradient
TomoTherapy Dosimetry Characteristics

IMAT Paper: Fig 7(b)
[Comparison of Plan Quality Provided by Intensity Modulated Arc Therapy and Helical TomoTherapy, Cao et al, IJROBP 69, 2007]
Beam Alignment and Radiation Tests

Front view

Jaws Define beam width (W)

Side view

Binary MLC

6 mm leaf resolution at isocenter

Laser alignment vs isocenter
Rotational Variation Test

Software driven output and energy checks can be achieved in one simple rotation (benefit of a single energy with high output of 6X)
Tomotherapy Automatic QA

- Step wedge check for output and beam performance correlation
- Beam quality check with on-board detector arrays (640 Zeon gas filled detector arrays)
- Chamber point measurement to acquire the absolute output value for IMRT treatment management
Tomotherapy QA Automation

223 diode detectors
- Sensitivity (32.0 nC/Gy)
- Detector size (0.64 mm²)

15 profiles analysis simultaneously
From TG-40 to TG-148 (Tomo QA) Requirement

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<tr>
<th>Frequency</th>
<th>Procedure</th>
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<td>Daily</td>
<td>X-ray output constancy</td>
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<td>Localizing lasers</td>
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<td>distance indicator (ODI)</td>
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<td>x-ray field symmetry</td>
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<td>Light/radiation field coincidence</td>
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<td>Gantry/collimator angle indicators</td>
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<td>Field size indicators</td>
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<td>Treatment couch position indicators</td>
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<td>Latching of wedges, blocking tray</td>
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<td>x-ray output calibration constancy</td>
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<td>Field size dependence of x-ray output constancy</td>
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<td>Central axis parameter constancy (PDD, TAR)</td>
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<td>Arc mode</td>
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<td>Collimator rotation isocenter</td>
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<td>Gantry rotation isocenter</td>
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<td>Couch rotation isocenter</td>
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<td>Coincidence of collimetry, gantry, couch axes with isocenter</td>
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<td>Coincidence of radiation and mechanical isocenter</td>
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Tomo TQA™ automates and simplifies the physics QA (Integrated)
Clinical MVCT Image QA Test

“Cheese Phantom” (Contrast and Resolution pattern with plugs)
Imaging Performance Characteristics

CT# Uniformity

-40
-30
-20
-10
0
10
20
30
40

0 5 10 15 20 25

Image #

Center - Edge CT# (HU)

CT# Uniformity Reference CT# Uniformity Final

Noise Uniformity

0
5
10
15
20
25
30
35
40

0 5 10 15 20 25

Image #

Center Noise - Edge Noise (HU)

Noise Uniformity Reference Noise Uniformity Final

512x512 matrix with 1.25 mm/lp resolution
Cranial Spinal Irradiation - Tomotherapy

- Large treatment volume
- Lengthy target coverage
- Treatment volume is irregular shape
- Many critical organs around
- Challenging dosimetry distribution
Cranial Spinal Irradiation - Tomotherapy
MVCT is implemented to identify the patient treatment location before each delivery
Simultaneous In-Field Boost (SIB) Tomotherapy

- IMRT Prescriptions:
  - GTV – 63 Gy
  - WB – 32.5 Gy
  - Hippocampus mean dose - 6 Gy
- Tomotherapy and Elekta VMAT techniques (Comparison)
- Jaw – 1.0 cm
- Pitch – 0.215, Modulation factor – 1.256 (set at 3.0)
- Delivery time – 16. minutes
Tomotherapy Planning Results

- Multiple brain lesions (GTVs) all receive 63 Gy focused radiation
- WB with uniform dose of 32.5 Gy while spares hippocampus to less than 6 Gy
Planning Outcomes with DVH

Hippocampus

Brain Mets GTV
VMAT plan
Hippocampus mean doses – 10.05 Gy (L), 9.90 Gy (R)

Tomotherapy plan
Hippocampus mean doses – 5.29 Gy (L), 5.18 Gy (R)
Arc Check Verification of Planning Results

> 98.9% passing rate
Each modality (GK/CK/Tomo) has its own strength in certain disease site (GK – intracranial, CK – intracranial, lung, spine…, Tomo – various diseases…)

Modern techniques of treatment (GK/CK/Tomo) have been developed with remarkable speed along with clinical protocols.

GK/CK/Tomo are designed to perform high precision treatments, with SRS/SRT/SBRT. QA process is important to assure high precision treatments.

Computer technology is the key for advanced treatment development, dosimetry accuracy and QA procedures are rudimentary for successful implementation.