What is Stereotaxis?

A Method for locating points within the brain using an external, three-dimensional frame of reference, usually based on the Cartesian coordinate system.
Delivery Techniques

- 201 (192) intersecting beams (Gamma Knife)
  - Spherical dose distributions
- Multiple arcs with circular collimators
  - Ellipsoid or spherical dose distributions
  - (0.5 cm to 4.0 cm cone)
- 11-15 fields shaped with mMLC or dynamic arcs
  - Arbitrary dose distributions (conformal)
- 1 to 2 proton fields

Indications

- Benign tumors (acoustic neuroma ….)
- AVMs
- Mets
- Boosts
- Salvage (e.g., recurrence after surgery and/or whole brain radiation)

What is Linac-Based SRS?

- Linac-Based SRS delivers a narrowly collimated x-ray beam while the gantry rotates around the target.
- Target is positioned at the center of gantry rotation.
What is Linac-Based SRS?

- Process is repeated for a number of treatment couch angles.
- Target is caught in a cross fire of x-ray beams, which delivers a lethal dose to the target (red) and spare the surrounding tissues.

Benefits

- Large dose to small (1-4 cm diameter) lesion with minimum dose to surrounding tissue.
- Single fraction - good for out-of-town patients, patients in poor health, or other patients who might be burdened by six weeks of treatment.

Prescription for SRS

- RTOG 90-05 recommendations:
  * 24 Gy for cones 1 - 2 cm
  * 18 Gy for cones 2.25 - 3 cm
  * 15 Gy for cones 3.25 - 4 cm
- Modify depending on disease radiosensitivity, prognosis, and other factors.
The first prototype of Leksell Gamma Knife was installed in Stockholm, Sweden, 1968.

Development of the Leksell Gamma Knife

- SRS was first introduced by Leksell in 1951.
- The first gamma knife: in the late 1960s.
- The second unit: in 1975.
  - Initially ~179 ⁶⁰⁰CO sources;
  - Currently (Model C) ~201 ⁶⁰⁰CO sources
  - Perfexion – 192 ⁶⁰⁰CO sources.

Model U
1994

Model C
2000

New Features with Leksell Gamma Knife C

- Operator console
- Automatic Beamforming System
- Color/cocktail estimator
- Leksell GammaPlan
- Hand control
- Integrated helmet changer

Designed for:
- Ease-of-use
- Safety
- Speed
- Selectivity
- Enhancements
Advantages of Model C

- Link between computer planning and treatment unit.
- Coordinates are set by the computer preventing human error.
- Collimator helmet is checked by the computer and treatment is not allowed unless the correct collimator is in place.

Advantages of Model C

- Treatment time is set by the software and cannot be changed by operator.
- A completed treatment with detailed information is stored in a read-only file for future reference.

Leksell Gamma Knife®
PERFEXION™
Leksell Gamma Knife®
Treatable volume

Leksell Gamma Knife® C
Leksell Gamma Knife® PERFEXION™

4, 8, and 16 mm

Leksell Gamma Knife®
Focus access

Leksell Gamma Knife® C
Leksell Gamma Knife® PERFEXION™

Dynamic shaping
Radiation protection

- Body doses up to 100 times less than from alternative technology
- Leakage levels low enough to allow for a window into the operating room
- Room design can be optimized to space and cost

What is Linac-Based SRT?

- Conventional fractionated treatment with non-invasive, reproducible stereotactic frame.

Prescription for SRT

- MDACC recommendation:
  - 30 Gy in 5 fractions, 6 Gy/fraction
  - Modify depending on previous treatment history, dose tolerance of critical structures, and other factors.
Stereotactic Instrumentation
(In-House)

Stereotactic Instrumentation
(Integra/Radionics)

Basic Requirements For SRS

- Mechanical precision
- Accurate localization
- Accurate and optimal dose calculation
- Patient safety
**Mechanical Precision**

- Linac gantry, collimator and couch
- Lasers
- Patient docking device
- Frame system
- Target verification device
- SRS system verification test

**Dose Measurements**

- Use AAPM TG-51 protocol
- Output, Central-axis %DD and TMR measurement - using PTW 0.1 c.c. Chamber or Scanditronix diode (For diameter ≥ 10 mm).
- Beam Profile - using film or stereotactic diode.
Quality Assurance for ImageFusion

Measuring MRI Distortion with a Phantom Head

During installation of the imageFusion system, a specially designed Geometric Phantom will be used to measure the spatial distortions inherent in the MRI scanner. These distortions will give an idea as to the magnitude of the errors to be expected. When scanning patients, use the same protocol that was used for the phantom, including slice spacing, slice thickness, field of view.

Use the phantom to test distortion on a periodic basis, particularly after a scanner system or software upgrade.

Spatial localization QA phantom
### Center of Sphere

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MU Calculation (for Arc)

Output @ isocenter
Ψ = S.F. * TMR
where S.F. = Scatter factor
Then, MU = D * w/ Ψ
where D = dose @ isocenter
w = beam weight ∝ arc length

Pre-treatment QA
Treatment

- Typically 5 arcs, about 40° ~ 60° each
- 300 MU/min ⇒ 1 ~ 2 min per arc
- Total treatment is 5 to 10 min of beam on time.
- Room entries between arcs to move couch and re-check patient alignment.
Computer-Controlled Miniature Multileaf Collimator (mMLC)

TYCO/RADIONICS

- Maximum Field Size: 13.5 cm x 11.3 cm @ isocenter
- Number of Leaves: 31 leaf pairs (62 leaves)
- Projected Leaf Width: 4.35 mm @ 100 cm SAD
- Each Leaf Travel (@ isocenter): 5 cm to 5 cm
- Leaf Transmit Time Rate: ~ 30 mm/sec
- Leaf Material: Tungsten Alloy (7 cm thick)
- Collimator to Isocenter Distance: ~ 37.5 cm
The reproducibility of each leaf is 0.2 mm ± 0.07 mm.

Uncertainty for the multiple scans on each set of leaf positioning tests is within 0.1 mm.
Clinical Applications

- SRS and SRT for intracranial tumors and metastases
- SRT for head and neck lesions
- SRT for the small tumors in the thorax and abdomen
Case Presentation

- **Primary Site and Histopathology:** Recurrent posterior fossa ependymoma
- **Stage:** Recurrent
- **History:** A 40-year-old gentleman who was initially seen in 1972 at the age of 15. He underwent a resection of his posterior fossa ependymoma and was treated with 36 fractions of external beam radiation therapy. He was without disease recurrence until 1998 when he noticed the onset of left facial paresis.

- **History (continued):** He had a repeat surgical resection at MDACC and the tumor was removed in the pontine and prepontine areas. Approximately two years later, regrowth was identified in 1993, and the patient underwent chemotherapy treatment over 12-month time and since that time slow progression of tumor has been noted. In early 1998, he had the onset of occipital pain and also also decreased function in the left hand.
History (continued): Although his tumor was relatively indolent but it had been increasing since 1993. Surgery and stereotactic radiotherapy (SRT) were presented to the patient at that time. Patient underwent serious injuries with his two previous surgeries and has expressed his desire for SRT.

MRI Finding: an MRI of the brain with & without contrast on 4/28/98, it showed a large nodular enhancing tumor in the prepontine cistern and the cerebral pontine angle predominantly on the left side.

Basic Treatment Plan: The recurrent tumor was treated to a total dose of 25 Gy in 5 fraction (twice per week). The dose was prescribed at the 90th percentile.
Case Presentation

- **Primary Site and Histopathology:** Carcinoma of the nasopharynx
- **Stage:** Recurrent (a recurrent mass filling the sphenoid sinus mostly on the left with possible invasion into left cavernous sinus.)
- **History:** A 47-year-old gentleman who had a history of T2, N1 carcinoma of the nasopharynx.

- **Previous Treatment:** (1997)
  - Radiotherapy - 70 Gy/35 fractions
  - Chemoradiotherapy - cis-platinum and 5-FU
- **Risk of Radiation Therapy:** Significant risk of left optic neuropathy and the optic chiasm has a low probability but real risk for neuropathy.
- **Basic Treatment Plan:** Treated with salvage radiotherapy to a dose of 70 Gy in 35 fractions.
**Diagnosis:** Meningioma of the right cavernous sinus

**Stage:** Locally recurrent

**History:** A male patient is now 12 years out from a previous surgery for a right cavernous sinus hemangioma. Serial evaluation by MRI for this process has revealed a slight interval growth in residual disease within this region in comparison to MRI that was performed in 2001. Although he remains asymptomatic, he will receive a course of definitive radiation in this setting to prevent further growth which could conceivably result in neurologic compromise.
Case (Continued)

- Basic Radiation Treatment Plan: The plan at this time will be to treat the area of recurrent meningoma within the right cavernous sinus. We will likely utilize stereotactic SRT to treat this region to a dose of 50 Gy in 25 fractions, precise aiming the lesion and sparing the optic nerves and optic chiasm.

Fused Images

GTV and Critical Structures on MRT Images
Objective

- Develop a non-invasive intracranial stereotactic radiosurgery technique with the same high degree of accuracy as that of the current invasive head-ring SRS Technique.
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Conclusions

- The image-guided non-invasive stereotactic radiosurgery has the capability of delivering high level accuracy of dose to the lesion without the pain and discomfort due to the pins fixed to the patient’s skull.
- Revise the fractionated SRT procedures by using image registration for the initial five treatments. Based on the variations of the isocenter, use the Ref isocenter for the remaining SRT treatments without performing the image registration process daily.

Thank you
Image-Guided Stereotactic Body Radiotherapy
(Featuring a 6D Robotic Couch-Top)

Almon S. Shiu, Ph.D
Radiation Physics Department
The University of Texas M.D. Anderson Cancer Ctr.
Houston, Texas

Research Team (2002)

Almon Shiu, Ph.D.
Eric Chang, M.D.
Jin-Song Ye, M.S.
Jim Lii, M.S.

Introduction

- Spinal metastases are a common component of metastatic disease afflicting 40% of all cancer patients which can cause severe pain, and neurologic sequelae
- Conventional radiation therapy widely used but is inherently limited by spinal cord tolerance leaving little possibility for re-irradiation in case of recurrence
- Stereotactic body radiotherapy (SBRT) is an emerging technology designed to precisely deliver higher doses, improve tumor control, and permit re-irradiation of the spine
Introduction

- Research workshop on 4/3/02 to propose the development of image-guided stereotactic body radiotherapy
- Phase I development finished in August, 2002.

Ongoing ID02-446 Clinical Trial

- Nov 2002 – SBRT first introduced to MDACC through Phase I/II clinical trial for patients with spinal or paraspinal metastases as a joint collaboration between Radiation Oncology, Neurosurgery, and Radiation Physics
- Primary objective to establish safety, feasibility, and efficacy using CT-on-Rails based SBRT to treat spinal and paraspinal metastases

Patient population

Protocol intended for patients with spinal metastases occurring in a variety of situations felt to be candidates after discussion in multidisciplinary tumor board

**GENERAL INDICATIONS**

**PRIMARY** - Newly diagnosed solitary or oligo-spinal metastases. “Radioresistant” subtypes

**POST-OP** – adjuvant or elective treatment

**SALVAGE** - surgical or RT recurrences
LINAC/CT-on-Rails Image-guided Stereotactic Body Radiotherapy

- Immobilization: Tyco/Radionics Body System™ consisting of a carbon base plate, vacuum cushions, a vacuum system and Fixation sheets.
- A Varian ExactCT targeting system – A GE CT scanner and a Varian Clinic 21 EX LINAC, shared the same couch between CT and LINAC.
- Treatment planning – IMRT
- Linkage between patient anatomy and stereotactic body frame and update daily isocenter based on 3D image fusion.


Spinal IMRT Radiotherapy

Treating Planning

- Prescription: 30 Gy/5 TX, 27 Gy/3 TX, or 18 Gy to 26 Gy/1 TX
- Beam Arrangement: 6- and 18-MV Photons

Axial and sagittal views of isodose distributions – normalized to GTV mean dose
- Typical prescribed dose to the volume included by the 90% isodose line
- The ultimate prescription dose was constrained by our IRB requirement for protocol approval that the dose to the spinal cord could not exceed a total of 10 Gy over five Tx (9 Gy over three Tx, 8 Gy over 1 Tx).
- Dose volume histogram - another way to evaluate the treatment plan

Isodose Distribution

Dose Volume Histogram

L1 (CTV)

RT Kidney

L2 Kidney

Cord

Carpal Tunnel

Dose (Gy)
IGSBRT – Treatment Process Flow Chart

Planning CT Scan

Frame

Plan Iso On Frame

Plan DRR

Daily CT Scan

Daily Iso

Daily DRR

Patient Positioning

Portal Images

Treatment Image Registration

DRR & Portal Registration

Anatomy Registration

Frame Registration

Portal Images

Daily Treatment Setup

Image-guided stereotactic Target alignment

CT imaging prior treatment

Fuse the planning images with the current CT images to calculate the shift and the rotation from the planning isocenter to the daily isocenter

Automatic On-Line Image Registration Based on Mutual Information

Automation of Image Registration And Verification for Image-Guided Stereotactic Body Radiotherapy

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DRR Comparison
Convention method: side-by-side comparison

By displaying two corresponding DRRs in one frame in a split screen format, sub-millimeter shifts can be readily detected.

Daily Treatment Setup
Image-guided stereotactic alignment

- Apply the shift from the planning isocenter and align the updated isocenter with lasers
Verify the target isocenter coincided with the LINAC radiation isocenter (Portal films)

Image-guided stereotactic alignment

Daily Treatment Setup

- Verify the target isocenter coincided with the LINAC radiation isocenter (Portal films)
Portal EPID Image Registration with DRR

• Deliver the IMRT treatment

• Repeat CT scan after treatment to confirm setup accuracy
Deviation from Planned Isocenter Using Daily Pre-treatment CT

Assessment of Setup Accuracy Using Immediate Post-Treatment CT

Phantom Study for HexaPOD Setup Accuracy
Portal Image Verification with DRR
Positioning Accuracy of Hexapod

After the automatic position of Hexapod, additional shifts needed for a perfect alignment (rounded to the nearest mm)

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Case1: 46 M previously irradiated (40 Gy in 16 fxs)
Lung cancer T12 metastasis progressed (biopsy proven)
Case 2: 52 M solitary renal cell carcinoma metastasis centered on cervical vertebrae 2
Case 3: 20 F plasmacytoma causing back pain

- Extradural extension causing cord compression at T10
- Needle bx revealed plasmacytoma
- 45 Gy in 25 fractions to T9-11 previous irradiated
- 3 mos later MRI - recurred below: Epidural dz T11-12.
  RT was not an option at the time
- Laminectomy, facetectomy, resection tumor
- 4 mo later recurred above: Rt T7-8 neuroforamen
- Received stereotactic radiation to epidural disease
- Attending college and remains disease-free 3 years later

Case 4: 48 F breast cancer

- Feb 03 - Metastasis at T9 previously irradiated at outside institution to 40 Gy/16fx/2.5Gy
- Feb 04 - MR progressive dz at T9, metastasis at posterior elements of T6. Worst pain 5/10
- Mar 04 - Pre-treatment PET/CT showed T9 SUV 6.2, T6 SUV 14.1
- Apr 04 - SBRT 20 Gy/5 fx given to T6 spinous process and T9 vertebra with pain relief
ACTUARIAL TUMOR CONTROL

Stereotactic Lung
Prescription: 50Gy in 5 fractions

ACTUARIAL TUMOR CONTROL

Stereotactic Lung
Prescription: 50Gy in 5 fractions
Conclusions

- Near-simultaneous CT image-guided verification technique can be used as a new platform technology for extra-cranial applications of stereotactic radiotherapy to spine and paraspinal tumors.
  - Treatment is totally non-invasive.
- The use of SBFS only can not achieve the setup accuracy comparable to that of intracranial SRS.
- The isocenter setup accuracy of image-guided stereotactic spine treatment is within 1 mm and comparable to the setup accuracy of intracranial SRS.

Conclusions

- The 3D navigation guided 6D robotic couch-top demonstrated that it could enhance the isocenter setup accuracy of image-guided body radiotherapy and improve the treatment-process efficiency.
- The automatic repositioning process could remove the possibility of the human errors for updating the target isocenter incorrectly.
Conclusions

Combine with 4-D CT to generate ITV and PTV, the image-guided Radiotherapy technique can be used to treat small lesions, e.g., lung, liver, kidney, etc.

Acknowledgements

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Brahman Gning

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Radhe Mohan, PhD
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Charles Washington

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