STEREOTACTIC TREATMENT
DEFINITIONS AND LITERATURE
OVERVIEW

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Radiosurgery Definitions

**Stereotactic/ Stereotaxy** : Clinical procedure based on reference markers to precisely locate a target within 3D-boundaries.

*Combine the use of a stereotatic apparatus & radiation beams*

**Two modalities:**

- **Stereotactic Radiosurgery - SRS**
- **Stereotactic Radiotherapy - SRT**
STEREOTACTIC RADIOSURGERY (SRS)

A “non-invasive” technique
Delivers of a single high dose of radiation
Limited, well-defined small intracranial target volumes
Avoids nearby normal tissue and critical structures
Minimize the dose to the adjacent brain tissue

STEREOTACTIC RADIOTHERAPY (SRT)

Employs same stereotactic techniques used for SRS
Refers to delivering collimated beams of radiation
in multiple fractions, to a stereotactically located target.
SRS-SRT

Two way process:

• Accurate shape definition and location of lesion and adjacent neuro-anatomy, from MRI, CT, CTA, Radiographic films, using stereotatic frame.

• Accurately delivery of a very conformal plan.
• SRS first developed by Leksell (late 1940’s) using orthovoltage X-Rays.
• Employed Heavy charged particles from cyclotrons.
• Gamma rays Gamma Knife (201 $^{60}$Co sources)
• Megavoltage X-rays from linacs (4 to 18 MV)
• First 3D treatment: Megavoltage unit, April 1948 (Kerst, 1975)
• First combined used of X-ray unit & stereotatic frame: Leksel, 1950
• High Doses (16 Gy to 22 Gy, generally prescribed to the 80% or 90%)
• Delivered in 1 fraction

• Mandate very rigorous, thorough and methodical QA.

• Written detailed procedures is mandatory.
Achievable uncertainties in SRS(*)

<table>
<thead>
<tr>
<th>CT slice Thickness</th>
<th>1mm</th>
<th>3mm</th>
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<tr>
<td>Stereotatic Frame</td>
<td>1 mm</td>
<td>1 mm</td>
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<td>Isocenter Alignment</td>
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<td>CT Image resolution</td>
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<td>Tissue Motion</td>
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<td>Angio (Pt. identification)</td>
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<td>Std. Dev. of Pos. Uncertainty</td>
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(*) AAPM Report No 54: Stereotatic Radiosurgery

CT slice Thickness
Linac Based (Xknife/Brainlab) vs Radioactive Source (Co) Gamma Knife

- **Collimator sizes:**
  - 4 to 45 mm in 2.5 mm steps
- **Conformal SRS:** with jaws/circles or MMLC; IMRT.
- **Extra-cranial:** head and neck; body localization: spine, prostate, lung, liver
- **Tx Room can be used for other Tx modalities.**

- **Collimator sizes:**
  - 4, 8, 14, 18 mm
- **Conformality is only attained through multiple isocenters**
- **No extra-cranial targets possible**
- **Requires dedicated Tx. Room.**
Gamma Knife
Stereotactic Radiosurgery - Linac Based

- A “non-invasive“ technique to deliver a single high dose of radiation, to limited, well-defined target volumes, while avoiding nearby normal tissue and critical structures.
Components of a Radiosurgery System

• Immobilization and Localization Instrumentation
  – Cranial
  – Head and Neck
  – Spine and Body

• Treatment Planning Software
  – Arcs, Conformal, IMRT, Frameless modules
  – Image Fusion™ software

• Linac and QA instrumentation
  Collimation System (MMLC, MLC, circular collimators, and circular collimators with linac jaws)
Stereotactic Hardware (Brain Lab)
m3 Linac Attachment

- Quick and easy mounting using a dedicated storage trolley
- Gantry at 180° position
- Immediate electronic and power connection
- Full communication and safety interlocks with Varian, Elekta and Siemens Linacs for IMRT and dynamic conformal arc treatment
m3 Linac Compatibility

**Trilogy & C-Series Clinacs**
- C-Series Clinacs
- Conformal Beam
- Dynamic Conformal Arc
- Sliding windows or Step & Shoot IMRT

**Oncor, Primus and Mevatron**
- Conformal Beam
- Dynamic Conformal Arc
- Automated Step & Shoot IMRT

**SL-Series**
- Conformal Beam
- Conformal Arc
Linac Compatibility

- Siemens: Oncor, Primus & Mevatron
- Varian (Trilogy & C-Series)
- TomoTherapy
- Elekta
Radiosurgery

m₃° mMLC

ExacTrac® X-Ray 6D
CHARACTERISTICS OF STEREOTATIC (SRS) and (SRT)

- **STEREOTACTIC COORDINATE SYSTEM**
  (CRW, BRW) → (CT, MRI, Angiography) → (Linac)
  allows accurate dose delivery to the target

- **SHARP DOSE GRADIENTS AT FIELD EDGES** :
  (Dose falls of to 50% of target dose within 3 - 4 mm)

- **HIGHLY CONCENTRATED RADIATION DOSE** :
  multiple non-coplanar arcs converging at the isocenter.
SRS/SRT General Procedure

• Diagnostic MR images of patient
• Target/Organs contouring
• Pre-plan using MR images (whenever allowed by Tx plan software)
• Placement of Head Ring
• Stereotactic CT/Angio images
• Transfer images to Tx Plan workstation
• Fuse MR to CT images (optional)
• Treatment Planning
• QA of LINAC (previous to Tx.)
• Verify correctness of Pt. Position
• Treat patient
Radiosurgery

Clinical Procedure

- Patient fixation: Start, 15 min.
- Imaging: 10 min.
- Planning: 30 min.
- Set-Up: 15 min.
- m3 Treatment: 30 min.
- Patient Treatment Completed
Cancer Management

- 60% of cancer patients undergo surgery
- 50% of cancer patients undergo radiation therapy
- 30% of cancer patients undergo chemotherapy
Rationale for Stereotactic Radiotherapy

- Reduces risk of healthy brain and cranial nerve damage
- Allows for treatment in/or near critical areas (e.g., retina, brain stem, chiasm)
- Allows for safe treatment of larger lesions (> 3-5 cm.)
Role of Radiosurgery in the Management of Intracranial Tumors

- Potentially curative therapy in benign, non-invasive tumors (pituitary adenomas, acoustic neuroma, meningioma, pilocytic astrocytoma).
- Adjuvant Therapy (Boost) for Benign or Malignant Tumors (metastasis, glioma, medulloblastoma, ependymoma).
- Preoperative Therapy for Vascular Tumors
- Salvage Therapy for previously irradiated recurrent tumors.
INDICATIONS FOR STEREOTACTIC SRS/SRT

- Acoustic Tumors (Schwannomas, Neuromas, Neurinomas, Nerve sheath tumors, Neurilemomas)
- Arteriovenous Malformations
- Arteriovenous Malformations
- Arterial Aneurysms
- Craniopharyngiomas
- Ependymomas
- Glomus Jugulare Tumors
- Hemangioblastoma
- Medulloblastomas (Boost)
- Meningiomas
INDICATIONS FOR STEREOTACTIC SRS/SRT

- Metastases
- Optic Gliomas
- Pinealomas
- Pituitary Adenomas
- Primary Brain Tumors (Glioblastomas, Astrocytomas, CNS Sarcoma, CNS Lymphoma)
- Retinoblastomas
- Venous Angiomas
- Functional Radiosurgery
- Clinical studies for use in Parkinson’s and Epilepsy
Typical Indications for Radiosurgery

Pre-SRS / 36 mth follow-up

Images courtesy of:
1) UCLA, 2) Universitätsklinikum Charité Berlin, 3) Helios Klinikum Erfurt, 4) University of Rochester

<DPF, NSUH-LIJ>
Radiosurgery - Metastasis

Pre-Radiosurgery

Post-Radiosurgery 6 months
Radiosurgery AVM

Pre-Radiosurgery

Post-Radiosurgery

6 months
Clinical Indications for SRS / SRT

- **Malignant Tumors, 50%** - Metastatic tumors, primary and recurrent gliomas
- **Benign Tumors, 25%** - Meningiomas, acoustic neuromas, pituitary adenomas, craniopharyngiomas
- **Vascular Disease, 15%** - AVMs, cavernous angiomas
- **Pediatric Tumors, 9%** - Retinoblastomas
- **Functional Disease, 1%**

1997 Study. Courtesy Jay Loeffler, M.D., Harvard Medical School, Boston, MA
Stereotactic Radiotherapy

- A hybrid technique that combines the benefits of conventional radiotherapy with the benefits of stereotaxy.
PHYSICAL COMPONENTS REQUIRED FOR SRS/SRT

1. Laser-Angiographic Target Localizer (LATL)
2. BRW (CRW) CT /MR Localizer Frame
3. Relocatable Head Frame (GTC)
4. Patient Positioning Devices:
   • Rectilinear Phantom Pointer (RLPP)
   • Laser Target Localizer Frame (LTLF)
   • Linac Couch Mount Adapter (LCMA)
5. Depth Confirmation Helmet (QA)
SRT (GTC) (Gill-Thomas-Cosman) relocatable head frame

SRS
Placement of Head Ring
Stereotactic Patient Set-up

CT Localizer

- For CT / X-Ray localization
- Links Angio Images to CT
- Creates stereotactic coordinate system
- Large scan range (185 mm)
- No fixation to CT couch
- Not required in MR
Stereotactic CT scan for SRS
PHYSICAL COMPONENTS REQUIRED
FOR SRT: Relocatable Head Frame (GTC)
Image Fusion

CT

MRI

Image Fusion
3 piece Mask System,
Extends treatment area to T1
Set-up errors from 1.7 to 0.9 mm
3 indexed differently sized bite plates
Complete carbon fiber,
Tilt compensation for set-up
Suitable for elderly patients & children

Patient positioning accuracy in a thermoplastic mask with upper jaw support.
J. Ahlswede et al. AAPM Annual Meeting 2001 Poster Display
PHYSICAL COMPONENTS REQUIRED FOR SRS/SRT TREATMENT PLANNING SYSTEM:

- Calculates and displays a 3D dose distribution based on the patient’s anatomy within the stereotactic frame
Basic requirements for SRS Dosimetry
(Linac Based)

• Accurate localization:
  – 1mm (angiography, CTA), 2mm (CT, MRI)

• Mechanical Precision: Stability of Linac
  – Gantry, Collimator & PSA axis of rotation (1mm radius).
  – Lasers: (2 Lats, 1 @ ceiling) Must be parallel and coincide @ isocenter <1mm.

• Accurate and Optimal Dose Distribution:
  – (<5%). Must be tested in humanoid phantom.

• Patient Safety:
  – Machine Interlocks. Gantry rotation, Secondary collimators & Couch motion disabled
  – Vernier based fine adjustment: allow alignment within ~1m
Stereotactic Set-up QA. (Linac)

Winston Lutz Quality Assurance

- Phantom Pointer verifies laser accuracy prior to SRS
- Embossed laser lines for easy alignment with wall lasers
- Integrated tungsten sphere for film verification
- Irradiation of film at different gantry angles
- Shadow in field center verifies accuracy
QA of Isocenter
SRX TARGET LOCALIZATION UNCERTAINTY

Machine: 600 C
SRX cone: 1.25 cm diameter.
SFD: 125 cm
Film type: X Omat L.
Monitor units: 4
Setup: Coordinates for SRX frames

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<th>AP</th>
<th>LAT</th>
<th>VERt</th>
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<tr>
<td>RLPP</td>
<td>0.00</td>
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<tr>
<td>LTLF</td>
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Patient coordinates notation: (supine configuration):
A: Anterior; P: Posterior; L: left; R: right; S: superior; I: inferior.

Procedure:
1. Laser wall marks verified.
2. RLPP set with laser target localization tool (lateral and ceiling lasers in the middle of the cross).
3. Vertical, longitudinal and lateral couch movements locked.
4. LTLF used to verify setup (Note: lateral lasers on the middle of lateral laser crosses. Ceiling laser displaced from center of the cross to the left line and superiorly out of the cross as regularly found on the anterior vertical vernier).
5. Laser target tool replaced by target localization ball.
6. LTLF removed and film irradiated as indicated in the following table.

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<td>AP(mm)</td>
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<td>---</td>
<td>+0.1 A</td>
<td>-0.7 P</td>
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<tr>
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<td>+0.2 R</td>
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<td>+0.5 R</td>
<td>-0.8 L</td>
<td>0.0</td>
<td>+1.2 R</td>
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<tr>
<td>SI(mm)</td>
<td>+1.0 S</td>
<td>0.0</td>
<td>+0.3 S</td>
<td>+0.4 S</td>
<td>0.0</td>
<td>+1.0 S</td>
<td>+0.4 S</td>
<td>-0.5 I</td>
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Note: Measurements done on the film (not at isocenter), using Wellhofer WP 700 film dosimetry program.

Detailed dosimetry results are attached to the original report kept in Radionics Acceptance Book (2001+).
QA of Pt Position

External Target
External Target Localization - Pt Position QA: Measure: BRW Localizer frame, on the CT & on the Tx. Plan

BRW Localizer Frame

External Target

RLPP
Stereotactic Frames and QA

Frames for SRS Applications:

Brown-Roberts-Wells (BRW)
Tipal
Leksel
Gill-Thomas-Cosman (GTC)
Riechert-Mundinger
Beam Dose Measurements

• Problem w/ small field dosimetry:
  – Detector size & Small field dimensions
  – Lack of equilibrium in lateral charged particles
  – Large dose gradients in SRS penumbra

• Equipment:
  – Water tank, polystyrene slabs, ion chamber, diodes, TLD’s and Film
  – Detector diameter < 3.5mm
    (reproduce penumbra ~1mm)
Measurement Summary

**Beam profiles:** Films, diodes, plastic scintillators, TLD’s.
Detector dimension < 2mm.
- Film is the dosimeter of choice. (Very good film processor a must)
- Diodes: care w/ angular dependence of response

- **TMR’s and Total Output Factors** \((S_t=S_c \ S_p)\): 
  Ionization Chambers, diameters < 3mm.
  - Ex: PTW Model 23342 Parallel plate
    Capintec cylindrical, vol= 0.07 cm³

- **Absolute Beam Calibration & output factor:** according w/ approved Protocol

- **Gamma Knife:** Same dosimeters but max. dosimeter dimensions no greater than 1mm x 1mm x 1mm
Pin-Point Chamber: Waterproof thimble chamber for measuring in air, water and phantom material:
  * Vented sensitive volume: 0.125 cm³ and 0.3 cm³
  * Suitable for use in water phantoms, w/ photons & electrons. Flat energy response within a wide energy range.
Beam Profiles

Coll=12.5mm

(a) Stereotactic Beam Profiles (12.5 mm coll)

Coll=22.5mm

(b) Stereotactic Beam Profiles (22.5 mm coll)

Coll=30.0 mm

(c) Stereotactic Beam Profiles (30.0 mm coll)

- Welhofer
- Laser Film Digitizer (Lumisys)
- Film Digitizer
Gamma Knife Beam profiles
TMR Curves
Stereotatic Output Factor Curve
\((S_t = S_c \cdot S_p)\)

@ Isocenter, \(d_{max}\)

6 MV
Coll. Diam.: 12.5mm to 20.0mm
Dose Evaluation Tools

• Volume Dose
• Surface Dose
• Dose Summary
• Slice Dose
• Dose Volume Histograms
• Tissue-Volume-Ratio (TVR)
Radiologic Physics Center (RPC)
Anthropomorphic Phantom

- Phantom has 2 inserts:
  - One for imaging: CT, MRI
  - One for Dosimetry w/ TLD’s and graphchromic film
PERSONNEL RESOURCES

Number of Hours Spent Per Treatment On Day Of SRS/SRT

- Radiation Oncologist 3.8 H
- Neurosurgeon 3.0 H
- Radiologist 0.7 H
- Physicist 6.1 H*
- Nurse 2.7 H
- RTT 2.0 H

*Individual Physicist time; since physics is involved in all aspects of the procedure total time is ~ 12 hours

- Larsen et al: Current Radiosurgery Practice: Results of an ASTRO Survey: IJROBP 28(2)523-526, 1994
Radiosurgery

Integration
Modular architecture for software and hardware integration

Upgradeability
- Continual software development
- Upgrade path for new features and applications

1997: m3
1998: Dynamic conformal arcs
1999: ExacTrac
2000: IMRT
2002: Novalis Body
2005: Adaptive Gating
**Dynamic Conformal Arcs**

- Automatic leaf adaptation to tumor contour
- Straight-forward arc optimization with collision map
- Possible with std. Varian MLC, m3 on Varian or Siemens Linacs

**Benefits:**

- Fast, semi-automatic single isocenter treatment planning
- Critical structures are automatically spared for all beam angles
- Most conformal and homogeneous dose distribution with reduced irradiation of normal tissue
Clinical Results

Conformal mMLC Plan
1 Isocenter - 6 Static Fields

Dynamic Conformal Arc Plan
1 Isocenter - 3 Dynamic Arcs

Volume of irradiated Normal Tissue (cm³)

50% Isodose 90% Isodose

6 Conf. Beams
3 Dynamic Arcs

4.64
3.69
0.64
0.53

Courtesy of Universitätsklinikum Charité, Berlin

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Clinical Results
Acoustic Neuroma

Circular Arc, 8 Isocenters
Conformal Beam, 19 Beams (1 isocenter)
Dynamic Conformal Arc, 5 Arcs (1 isocenter)

7.2 Gy
18.0 Gy
4.0 Gy
10.0 Gy
18.0 Gy

Improved normal tissue sparing
Tight margin around target
Clinical Results
Acoustic Neuroma

Homogenous Dose Distribution
Greater sparing of normal tissue and risk structures

Strong Growth

\[\text{(€)}\]

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Thank you