Not for the Faint of Heart: Functional Radiosurgery

Functional radiosurgery with Gamma Knife

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Conflicts of interest

No conflicts

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Learning Objectives (for this section)

1. Review some less common functional indications treated with Gamma Knife Radiosurgery
2. Understand how the design of the Gamma Knife supports its use for functional SRS
3. Summarize some important techniques that can help mitigate treatment risk when treating functional SRS on the Gamma Knife platform

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Part 1: Indications

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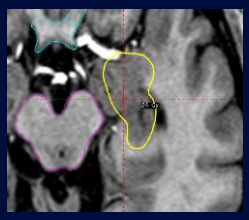
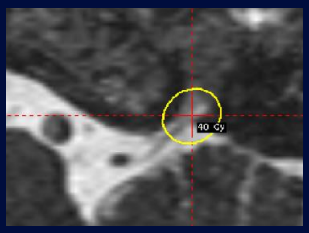
Gamma Knife functional SRS indications

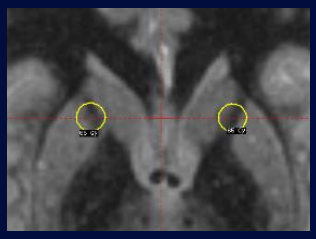
Trigeminal neuralgia
max dose: 75-90 Gy



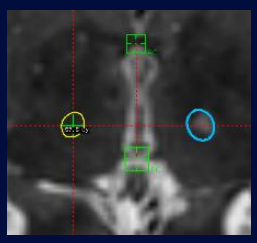
Mesial temporal lobe epilepsy
max dose: 48 Gy



Glossopharyngeal neuralgia
max dose: 75-90 Gy



Obsessive-compulsive disorder
max dose: 120-180 Gy



Movement disorders
max dose: 120-140 Gy

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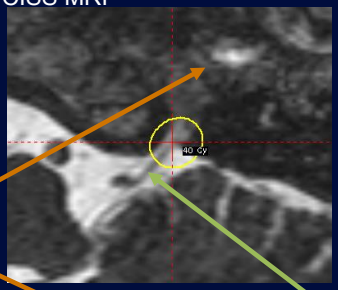
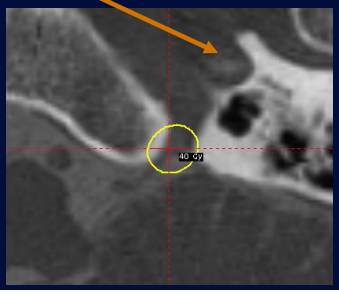
Glossopharyngeal (CN IX) neuralgia

CISS MRI



Carotid artery

CISS/CT fusion



Glossopharyngeal nerve

Stabbing pain similar to trigeminal neuralgia, but affects ear, tongue, and throat.

Target is the glossopharyngeal nerve at the level of the glossopharyngeal meatus of the jugular foramen.

Difficult to visualize so CT/MR fusion often used.

Single 4mm isocenter used for treatment.

~80 Gy maximum dose (similar to trigeminal neuralgia SRS)

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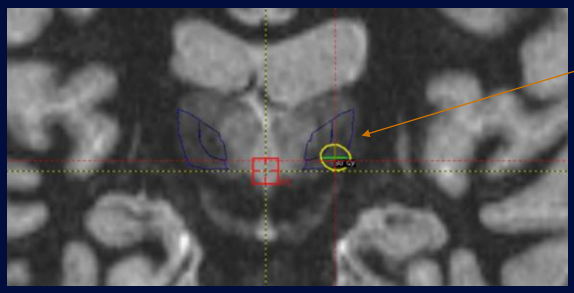
Movement disorders (essential tremor, Parkinson's disease)

Goal is to modulate motor fibers running from the thalamus to the motor cortex (radiosurgical thalamotomy)



FGATIR MR – coronal view

nucleus ventralis intermedius (Vim) of thalamus

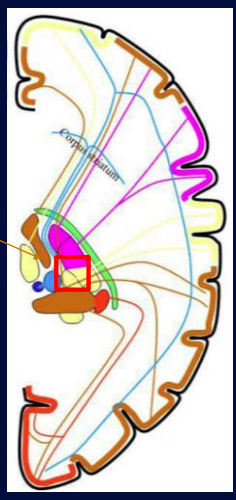


Figure from B-K Min, Theoretical Biology and Medical Modelling 7(10), 2010

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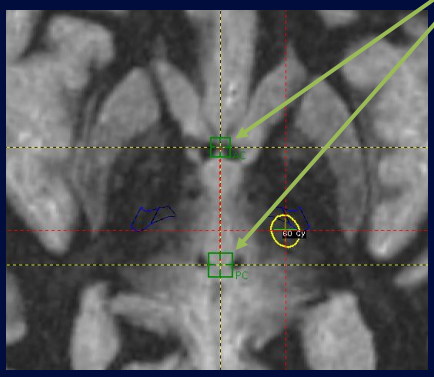
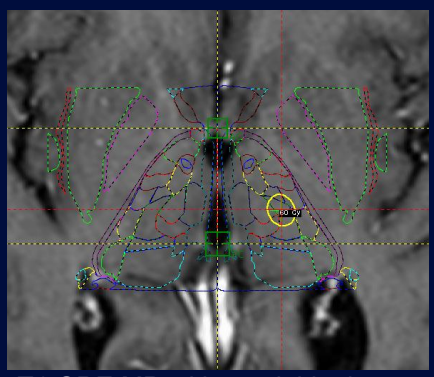
Targeting the VIM nucleus

VIM nucleus difficult to visualize. Targeting performed using Talairach atlas-derived rules:



FGATIR MR

1. Define AC-PC line and interhemispheric fissure
2. Lateral (X): 50% of 3rd ventricle width + 11 mm
3. Anterior (Y): 25% of the distance from PC to AC
4. Superior(Z) : 2mm superior of AC/PC line
5. Single 4mm isocenter
   Max dose = 120-150 Gy



T1 GRE MR with overlaid atlas

A. Niranjan, et al., Movement Disorders 32(5), 2017.

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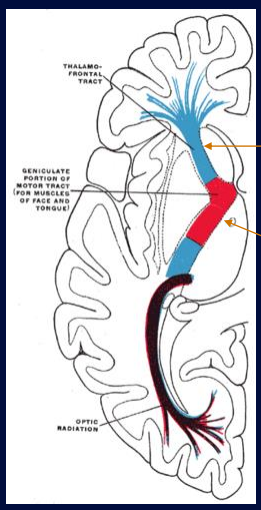
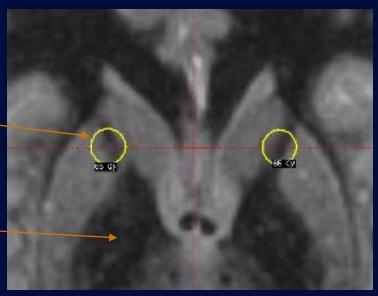
Obsessive Compulsive Disorder

Goal is to modulate sensory fibers running from the thalamus to the orbitofrontal cortex (radiosurgical capsulotomy)



Internal capsule (anterior limb)

Internal capsule



Lesions are targeted at the anterior limb of the internal capsule

Usually single 4mm isocenter each side
Max dose = 120-180 Gy (IRRF multicenter study median 135 Gy†)

Image from: https://psychology.wikia.org/

†A. Gupta et al., Neurosurgery 85(6), 2019

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Part 2: Gamma Knife and functional SRS

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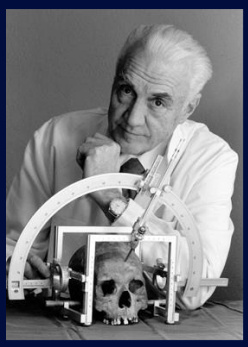
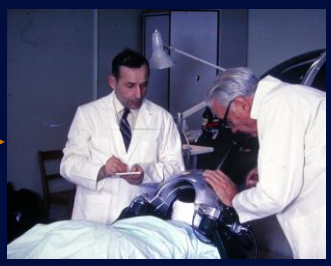
Functional radiosurgery is the original radiosurgery!



(image courtesy of Elekta, AB)

Lars Leksell with arc-centered stereotactic frame



Gamma Knife with external collimator helmet (with Lars Leksell and Ladislau Steiner at the Karolinska Institute)

Close-up view of rectangular collimator apertures

Designed to create radio-lesions similar to proton experiments

Leksell, L. 1971. *Stereotaxis and Radiosurgery: An Operative System.* Springfield: Thomas Publishing.
J. Gantz, The History of the Gamma Knife, Progress in Brain Research 215, 2014.

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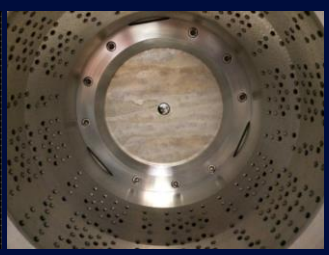
Spreading out energy is the key to SRS

Image courtesy of Elekta, AB



University of Virginia

Technical requirement to create many individual small beams led directly to the use of ^{60}Co

Spreading the energy out generates steep dose gradients that concentrates dose on the target

Perfexion/Icon: 192 beams / isocenter
Total # beams in plan = # isocenters * 192 (if no blocking)

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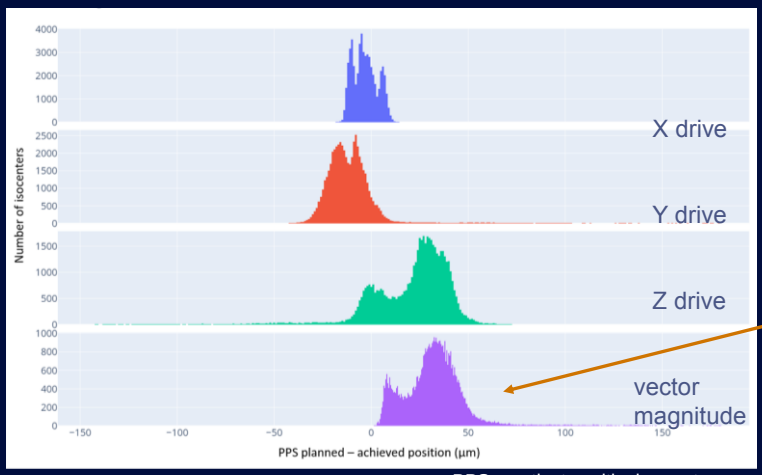
Patient positioning accuracy and precision

Planned – achieved PPS position (μm)



n=53833 shots
(8.3 years)

Mean PPS difference:
32.7 μm

97.5% of all shots
within 70.1 μm

Human hair ~75 μm

PPS = patient positioning system

Schlesinger, et al., Med Phys, 2021 (in-press)

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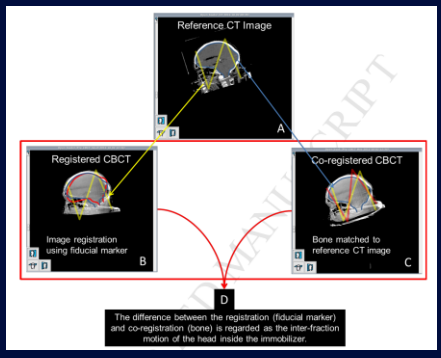
Stereotactic frames provide immobilization



SRS frames provide for low setup uncertainty and robust immobilization.

Practically limits treatment to single fraction.

Looks more invasive than it really is.

	Setup Error							Intrafraction Error						
	Translation (mm)				Rotation (°)			Translation (mm)				Rotation (°)		
	LR	AP	CC	Vector	LR	AP	CC	LR	AP	CC	Vector	LR	AP	CC
Mean	-0.19	0.08	-0.35	0.40	-0.14	-0.03	0.10	-0.03	-0.03	-0.03	0.05	-0.05	-0.03	-0.01
SD	0.32	0.29	0.50	0.66	0.25	0.19	0.20	0.05	0.18	0.12	0.22	0.30	0.20	0.09

Li, et al., IJROBP 2016.

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Part 3: Imaging for functional SRS

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Steady-state sequences (CISS/SPACE/FIESTA-C)

T2 SPACE image showing good visualization of trigeminal nerve

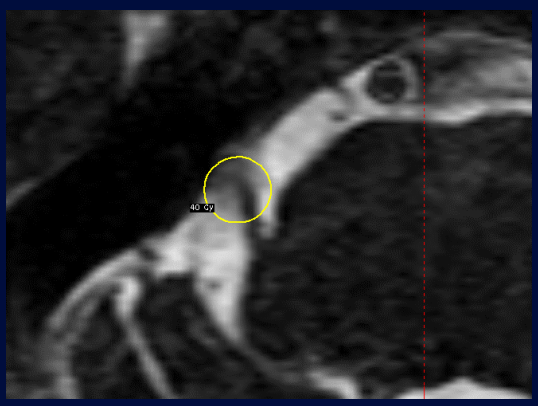

Image courtesy of University of Virginia

CISS: Constructive Interference in Steady State

SPACE: Sampling Perfection with Application-optimized Contrasts by using different flip-angle Evolutions

FIESTA: Fast Imaging Employing Steady-state Acquisition

Use RF-pulses to refocus echos and maintain a steady-state net magnetization

Creates bright CSF signal, dark tissue

Good for visualizing fine structures in CSF

S. Stuckey, et al., AJNR 18, 1996

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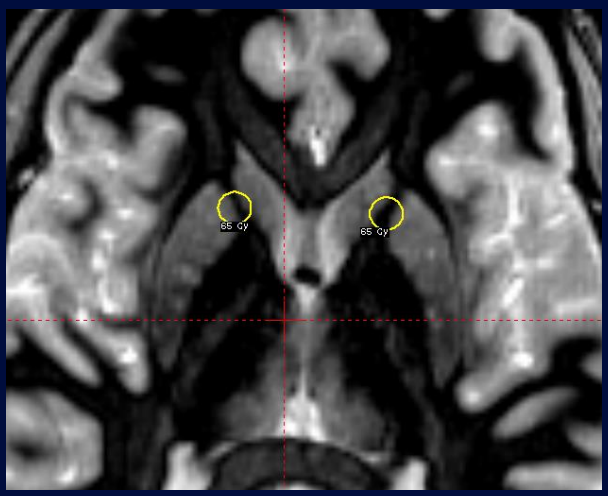
Specialized sequences: FGATIR



FGATIR image used for an OCD treatment

Image courtesy of University of Virginia

FGATIR: Fast Gray Matter Acquisition T1 Inversion Recovery

Similar in idea to MP-RAGE, but selected inversion time (TI) nullifies white matter signal

Allows better visualization of deep grey matter structures

A. Sudhyadhom, et al., Neuroimage 47, 2009.

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Part 4: How to be safe

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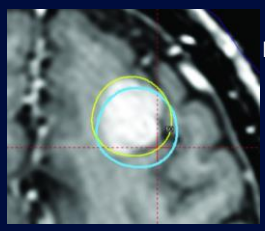
Stereotactic frame QA with onboard CBCT

Stereo CT

Icon CBCT



Dose error

Icon CBCT scans are acquired in stereotactic space.

Can be used as an independent measure of spatial localization.

We use it as a last-chance QA that all is well with the frame placement.

M.S. Peach, et al., JRSBRT 5(4), 2018.

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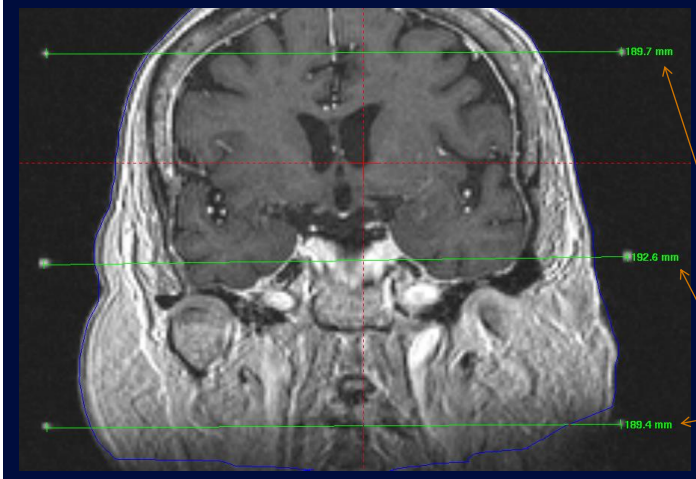
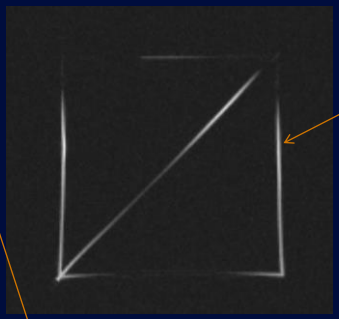
Don't forget imaging QA!





These should be straight lines!

These distances should be the same!

Regular QA of imaging systems is critical for SRS!
This includes after hardware/software upgrades.

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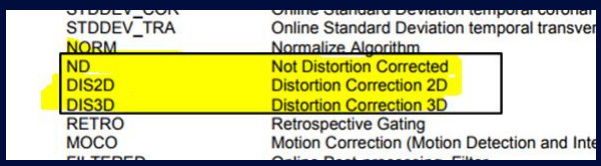
Make sure distortion correction is applied!

A.7.1 Image Type

The Image Type (0008, 0008) attribute identifies important image identification characteristics.



STDDEV_TRA	Online Standard Deviation temporal transver
NORM	Normalize Algorithm
ND	Not Distortion Corrected
DIS2D	Distortion Correction 2D
DIS3D	Distortion Correction 3D
RETRO	Retrospective Gating
MOCO	Motion Correction (Motion Detection and Inte

Example: ORIGINAL | PRIMARY | M | NORM | DIS2D

SIEMENS

syngo® MR D13

[redacted] MR

DICOM Conformance Statement

MRI is subject to system-level and patient-specific distortions.

Manufacturers have corrections for some system-level causes (gradient nonlinearities).

Make sure they are commissioned and applied!

We find it useful to compare to CT.

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Learn from collective experience

An International Radiosurgery Research Foundation Multicenter Retrospective Study of Gamma Ventral Capsulotomy for Obsessive Compulsive Disorder

Amitabh Gupta, MS, MCh, Matthew J Shepard, MD, Zhiyuan Xu, MD, Tanmoy Maiti, MD, Nuria Martinez-Moreno, MD, PhD, Joshua Silverman, MD, PhD, Christian Iorio-Morin, MD, PhD, Roberto Martinez-Alvarez, MD, PhD, Gene Barnett, MD, David Mathieu, MD, Hamid Borghei-Razavi, MD, PhD, Douglas Kondziolka, MD, Jason P Sheehan, MD, PhD ✉

Neurosurgery, Volume 85, Issue 6, December 2019, Pages 808–816,

NEUROSURGERY

Stereotactic radiosurgery for idiopathic glossopharyngeal neuralgia: an international multicenter study

Hideyuki Kano, MD, PhD,[1] Dusan Urgosik, MD,[2] Roman Liscak, MD,[2] Bruce E. Pollock, MD,[3] Or Cohen-Inbar, MD, PhD,[4,7] Jason P. Sheehan, MD, PhD,[4] Mayur Sharma, MD,[5] Danilo Silva, MD,[5] Gene H. Barnett, MD,[5] David Mathieu, MD,[6] Nathaniel D. Sisterson. BA.[1] and L. Dade Lunsford. MD[1]

J Neurosurg (Suppl 1) 125:147–153, 2016

JNS JOURNAL OF NEUROSURGERY
OFFICIAL JOURNALS OF THE AANS SINCE 1944

Data is sparse for many functional indications.

Multi-center studies may provide helpful guidance.

If you experiment, formalize as an approved clinical trial!

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Follow consensus recommendations

MEDICAL PHYSICS
The International Journal of Medical Physics Research and Practice

AAPM SCIENTIFIC REPORT | Full Access

Recommendations on the Practice of Calibration, Dosimetry, and Quality Assurance for Gamma Stereotactic Radiosurgery: Report of AAPM Task Group 178

Paula L. Petti, Mark J. Rivard, Paola E. Alvarez, Greg Bednarz, J. Daniel Bourland, Larry A. DeWerd, Robert E. Drzymala, Jonas Johansson, Keith Kunugi, Lijun Ma, Sheridan G. Meltsner ... See all authors

First published: 10 March 2021 | https://doi.org/10.1002/mp.14831

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Require credentialing and training

Quality and Safety Considerations in Stereotactic Radiosurgery and Stereotactic Body Radiation Therapy

Timothy D. Solberg, Ph.D.[1], James M. Balter, Ph.D.[2], Stanley H. Benedict, Ph.D.[3], Benedick A. Fraass, Ph.D.2, Brian Kavanagh, M.D.[4], Curtis Miyamoto, M.D.[5], Todd Pawlicki, Ph.D.[6], Louis Potters, M.D.[7], Yoshiya Yamada, M.D.[8]

and physicist / neurosurgeon

"If the radiation oncologist's formal training did not include SRS/SBRT, then specific training in SRS/SBRT, including a minimum of 5 CME credit hours and direct observation of treatment of at least 3 different patients, should be obtained prior to performing any SRS or SBRT procedures"

Even more critical for functional SRS!

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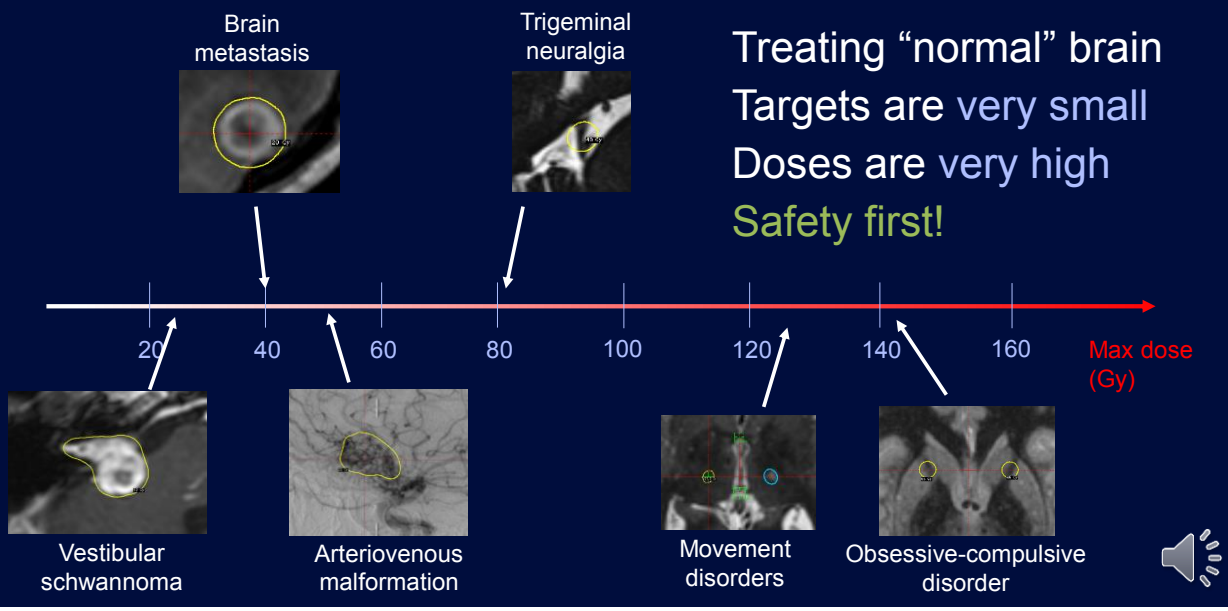
Summary: Functional radiosurgery really is different!



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Thank You!

Acknowledgements

University of Virginia
Jason Sheehan
Zhiyuan Xu

Elekta Instrument, AB
Håkan Nordström
Jonas Johansson

NOT safety first! Don’t do this!
(unless the unit is unloaded!)

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