Intracranial Stereotactic Radiosurgery
Concepts and Techniques

Antonio A.F. De Salles, MD, PhD[a,b,*],
Alessandra A. Gorgulho, MD, MSc[a,b],
Julio L.B. Pereira, MD[a,b], Nancy McLaughlin, MD[a,b]

KEYWORDS

• Stereotactic radiosurgery • Gamma Knife • Linear accelerator • Novalis • Cyberknife
• Tomotherapy

KEY POINTS

Readers of this article will learn:

- The history of device development for radiosurgery.
- The technical nuances of each intracranial radiosurgery device.
- Step-by-step performance of a radiosurgery procedure.
- The need of a team approach in radiosurgery.
- The expansion of intracranial radiosurgery to other areas of the body.

INTRODUCTION

Stereotactic radiosurgery evolved based on two good ideas. First, treating a lesion in human tissues with external beam radiation, described by Kohl 18 years after the discovery of X-rays.[1] The second hinged on the work of Horsley and Clarke, neurosurgeon and mathematician, respectively, who developed a tool to localize intracranial structures in three dimensions. This work resulted in a stereotactic atlas of the primate brain published in 1908. An atlas that combined the use of this development was the subject of Spiegel's reported human stereotactic atlas in 1952.[2,3]

The concept of applying focal X-rays as a therapeutic tool evolved using spiral converging beams, pendulum-directed beams, and finally rigid hemispheric distributed beams directed with stereotactic precision.[4] It was Lars Leksell, a practicing functional neurosurgeon at Karolinska University in Stockholm, Sweden, who integrated stereotactic precision with the penetrating capability and the tissue effect of the photon beam. As widely described, Leksell attached an X-ray tube to his stereotactic arc centered frame and delivered radiosurgery to the first patient submitted to the technique, targeting the trigeminal ganglion for treatment of trigeminal neuralgia. The term "radiosurgery" was coined.[2]

Radiosurgery evolved during the last half of the twentieth century linked to the explosion of imaging techniques.[5] Because it was dependent on ventriculography, cysternography, and angiography, the applications of radiosurgery were largely limited to pathologies visualized by these techniques. Functional applications were based on principles of functional neurosurgery localization, for example using the anterior commissure and

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[a] Department of Neurosurgery, David Geffen School of Medicine, University of California Los Angeles, Los Angeles, CA 90095, USA; [b] Department of Radiation Oncology, David Geffen School of Medicine, University of California Los Angeles, Los Angeles, CA 90095, USA
* Corresponding author. Department of Neurosurgery, David Geffen School of Medicine, University of California Los Angeles, 10495 Le Conte Avenue, Suite 2120, Los Angeles, CA 90095.
E-mail addresses: afdesalles@yahoo.com; adesalles@mednet.ucla.edu

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posterior commissure seen by ventriculography to guide targeting. Meckel cave contrast material injection and cysternography provided visualization of targets, such as the trigeminal ganglion in the Meckel's cave and the acoustic neuroma's prominence in the cerebellopontine angle, previously not seen in plain skull radiographs.[6] Angiography provided the visualization of arteriovenous malformations (AVMs), making them the classic application of radiosurgery starting in 1972.[7] The buildup of radiosurgery applications with the introduction of structural diseases, such as acoustic neuromas and AVMs, increased the demand for affordable radiosurgery throughout the world. During the early 1980s there were less than 10 radiosurgery devices serving the world's population: three Gamma Knives and a few proton facilities.

Modern neurosurgery develops toward minimally invasive procedures, therefore radiosurgery has gained space. The multidisciplinary nature of the procedure involving the neurosurgeon, radiation oncologist, and medical physicist aims to minimize the risks and to improve the treatment success rate. This has been met with great acceptance by patients and payers alike. Radiosurgery has an important therapeutic role in the management of brain tumors, AVMs, and trigeminal neuralgia, and continues to expand its applications, including selected functional disorders of the brain, such as epilepsy.[8,9]

The success of intracranial radiosurgery has also spread to the spine and other areas of the body,[10] revolutionizing the practice of radiation oncology. The same impact of radiosurgery in general neurosurgery is being repeated in other surgical specialties, such as thoracic surgery.[11] The clinical importance of radiosurgery expedited the development of new technologies capable of increased speed, comfort, and effects of radiosurgery for its diverse applications.

Today there are four major photon energy radiosurgery devices competing in the market based on advantages and disadvantages of respective intended specific applications and strategies of planning the treatment (**Table 1**). Regardless of the approach, the fundamental concepts of radiosurgery include high doses of radiation, minimal doses in surrounding structures, stereotactic localization, use of computerized dosimetry planning, and a highly accurate radiation delivery system.[12–14]

BASIC CONCEPTS

Ionizing Radiation

Ionizing radiation for radiosurgery is any radiant entity that has enough energy to remove an electron from an atom, thus creating ions, which interact with the living tissue in the target generating a biologic response. Gamma rays are

Table 1
Summary of the capabilities of each technique routinely used for stereotactic radiosurgery and stereotactic radiotherapy planning

Modality	Indications	Key Features	Limitations
Circular collimator (single)	Small round targets, functional radiosurgery applications	Fast delivery, usually homogeneous (if diameter ≥10 mm)	Limited to small and round targets, rapid planning
Multiple isocenters	Small-to-medium irregularly shaped target	Conformal, inhomogeneous	Slow delivery, inhomogeneous, time-consuming planning
Dynamic-shaped beam	Small-to-medium irregularly shaped target	Conformal, homogeneous, fast radiation delivery	Loose conformality with large targets because of beam overlap
Static-shaped beam	Large irregularly shaped target	Conformal, homogeneous, fast radiation delivery	More dose through the path of the beam, usually time-consuming planning
Pencil beam painting	Irregularly shaped target	Conformal, homogeneous	Slow radiation delivery
Intensity modulation	Large irregularly shaped target	Conformal, tighter dose distribution, better sparing of organ at risk	Slow radiation delivery, usually inhomogeneous, strict delivery quality control