Imaging of vestibular schwannomas following γ-Knife treatment – a series of 79 cases

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Abstract

Gamma-Knife became an established therapeutic alternative for selected cases of vestibular schwannomas (benign tumors rooting from Scwann cells of vestibular nerve). However, the long term results and effects on the tumor and surrounding brain are still a matter of research. We analyze the imagistic findings in the patients with vestibular scwannomas treated with gamma-knife radiosurgery in the Gamma-Knife Department, Hygeia Hospital, Athens.

We performed radiosurgery on 79 cases of vestibular scwannomas. 23 of them were first operated with incomplete resection and had gamma-knife performed on residual tumor. Of all cases, one patient died 4 years after the treatment, while 4 cases didn't comply with the follow-up protocol and were excluded from the study. The other cases underwent a follow-up protocol with MRI sudies at 6, 12, 18, and 24 months following the gamma-knife session. We looked at the tumoral volume, and the evolution of the tumor in relationship with the iradiation dise and isodose curve.

Our results confirm the landmark results of Karolinska an Pittsburg studies. We show that small gamma-knife doses are suitable for a satisfactory control of tumoral volume. Stereotactic MRI imaging and multiple doses programs are the main factors contributing to these results.

Keywords: vestibular schwannoma, radiosurgery, gamma-knife, MRI

Introduction

Histologically, vestibular schwannomas are benign tumors that grow from the Schwann cells of the 8th cranian nerve. Due to improved neuroimaging the incidence of vestibular schwannomas within the general population increased.

However, despite the advances in introperatory techniques, surgery still carries a risk for morbidity and moratality. Depending on tumors characteristics vestibular schwannomas can be treated by different methods, other than neurosurgery. Radiosurgery is one of these non-invasive techniques that can be used to treat vestibular schwannomas. It uses gamma radiation (photons) and is known as "Gamma-Knife" or "γ-Knife".

We analyze the imagistic findings in the patients with vestibular scwannomas treated with gamma-knife radiosurgery in the Gamma-Knife Department, Hygeia Hospital, Athens.

Our results point to the fact that using small doses of radiation (similar to those used in the reference series from Karolinska and Pittsburg) can control the volume of the lesion as shown by the follow-up controls results. Stereotactic MRI and a

multiple dosage program seem to be the main factors in achieving this result. According to published results the method can fail if the doctor decides not to partially exclude the lesions localized ar superior limit of the treated region.

Materials and method

In the last six years (February 2004 – September 2010) 79 cases of vestibular schwannomas have been treated with gamma-knife radiosurgery in our unit. 23 patients have undergone surgery prior to gamm-knife, and had radiosuergery as an adjuvant therapy on remnant tumor. One patient died 4 years after the gamma-knife treatment because of pre-existing cardiac co-moribidities. 4 patients failed to comply woth the follow-up rpotocol and were excluded from our study. 2 patients declared that their quality of life deteriorated as a result of radiosurgery.

To study the effects of radiation therapy the patients had to comply with a follow-up protocol that included MRI studies at 6, 12, 18, and 24 months after the treatment. The goal of follow-up was to monitor the volume of the schwannoma and to analyze the imagistic aspects as a result of gamma-knife therapy. The radiation dose (Gy) and radiation isodose curve have been measured in relationshipwith their effect in controling the progress of the tumors.

The average age of the patients included in our study was 55 years (22-74). Out of 79 cases 9 presented intracanlicular tumors, 19 developed intracanalicular and cisternal tumors, while 51 presented with tumors occupying the cerebello-pontine cistern (table 1.). the main tumor volume (Vm) was 4.72 cm³ (0.2-19.3 cm³). The female to male ration was 51:28.

TABLE 2

Characteristics of the 79 vestibular schwannoma patients that underwent gamma-knife surgery

Parameters	Values
Median age (interval)	55 (27 - 74)
Female to male ratio	51:28

Tumor localization
    intracanalicular
    cerebello-pontine cistern
    both cisternal and
    intracanalicular
	9
	51
	19

Previously treated	23
Medium colume in cm³ (interval)	4,72 (0,20-19,3)

Gamma-knife therapy particularities

Gamma-knife radiosurgery is base on four principles:

1. "Target" localization, using neuro-imagistic techniques, a stereotactic frame, and computer software to record and alter imaging data.

2. Computing lesion volume

3. Determining the distribution of radiation dose

4. Radiotherapy

During a radiosurgery session the median of isodose curve was 48.25%, with an interval of 40-54%.

Target localization is extremely important and excluding important cranial structures from being exposed to the gamma radiation (such as cranial nerves, cerebellum, and of course brain stem).

During treatment average marginal dose was 12.09 Gy (11 – 14 Gy), and maximal average dose was 19.83 Gy (20.5 – 29.9 Gy). Average tumor volume of treated

schwannomas was 4.72 cm^3 (0.2 – 19.3 cm^3).

To protect the undefined segments of the facial and trigeminal nerves that are prone to be included in the designated lesion volume, we administered in these areas doses below 13 and 15 Gy respectively. In two cases where the tumor had an occupying effect involving the brainstem the same dose didn't reach more than 10 Gy. All patients responded well to the treatment and were released the next morning after treatment completion. None reported neurological problems during hispitalization (such as epileptic seizures). Headache was present in 12 cases, most likely due to the steretactic frame. To address these headaches patients were given oral pain killers for a short period of time (2-3 days) in the period following their release.

Follow-up

All patients, with one exception, underwent MRI imaging 6 months after the treatment. Six of them didn't present for the next follow-up session, at 12 months. MRI evaluation criteria included:
• Changes in the volume of the vestibular schwannoma
• Neuro-imagistic findings like: loss of central enhance (necrosis), local swelling through the cerebral ventricular system.

Results

The average follow-up period was of 24 months (1 – 51). 84.2% of the patients performed at least one MRI exploration at 6 months.

MRI evaluation

The solid part of the tumor reacted satisfactory to gamma-knife iradiation. As documented by the MRI images in the first six months this response takes the shape of a central region of necrosis (seen in T1). Acording to published data this phenomena is noticed from the first month (or later than 23 months) and can extend within the tumor in the next 10 months (or even later than 60 months) after the treatment. A small percentage of the patients (11,8%) showed a swelling of the lesion. MRI findings at first follow-upmatch those reported in the literature in 34 cases. Only 2 cases showed a significant change in lesion volume in the 24 months period following gamma-knife therapy (from 0.71 cm3 to 1.1 cm3, and from 19.3 cm^3 to 23.1 cm3), while the maximum reduction in tumor volume recorded in our series was from 12.4 to 2.7 cm^3.

Discussion

Optimal radiation dosage for tumor control

Optimal radiation dosage for vestibular schwannoma control is still a matter of debate. A review of the literature showed a tendency to decreasing prescription dosage from 25-100 Gy used in the initial studies to 13 Gy in the current protocols. Nóren, et al. have prescribed dosages of 25-35 Gy to the tumor periphery to ensure stopping tumor growth. However, high dose radiation has led to high morbidity due to facial and trigeminal nerve damage. In addition, possible preservation of hearing may be compromised when using a high dosage. First of all, a reduced radiation dose lowers the probability of cranial nerve neuropathy. Second of all, small doses have a better chance, at least in theory, to preserve hearing close to preoperative levels. Third of all, a lower dose should theoretically reduce or minimize the degree of swelling of the tumor that may occur after treatment.
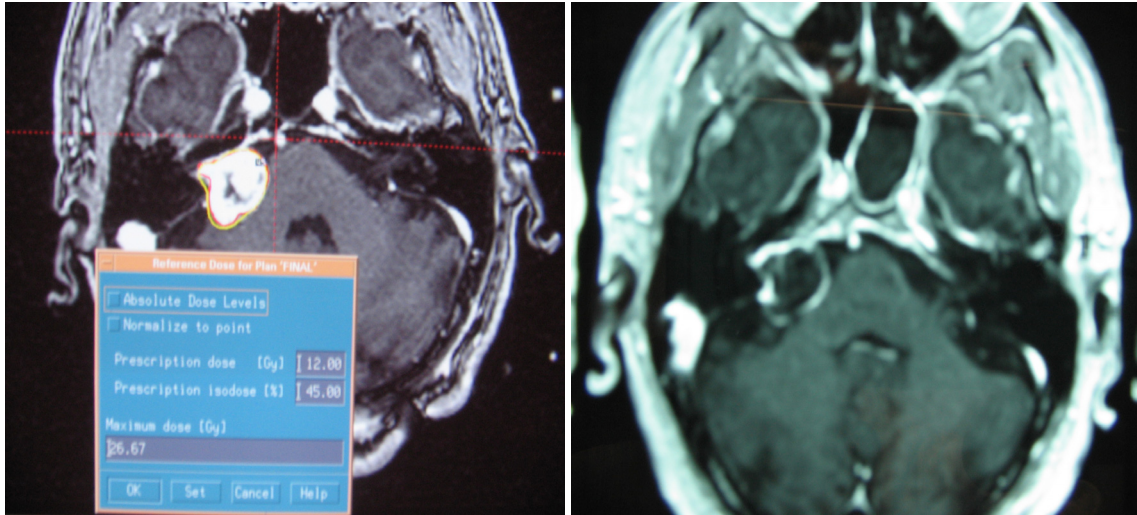
Figure 1 Left: Male, 62 yrs. Old, before therapy. Dose 12Gy (45%), volume 3,4 cm³.
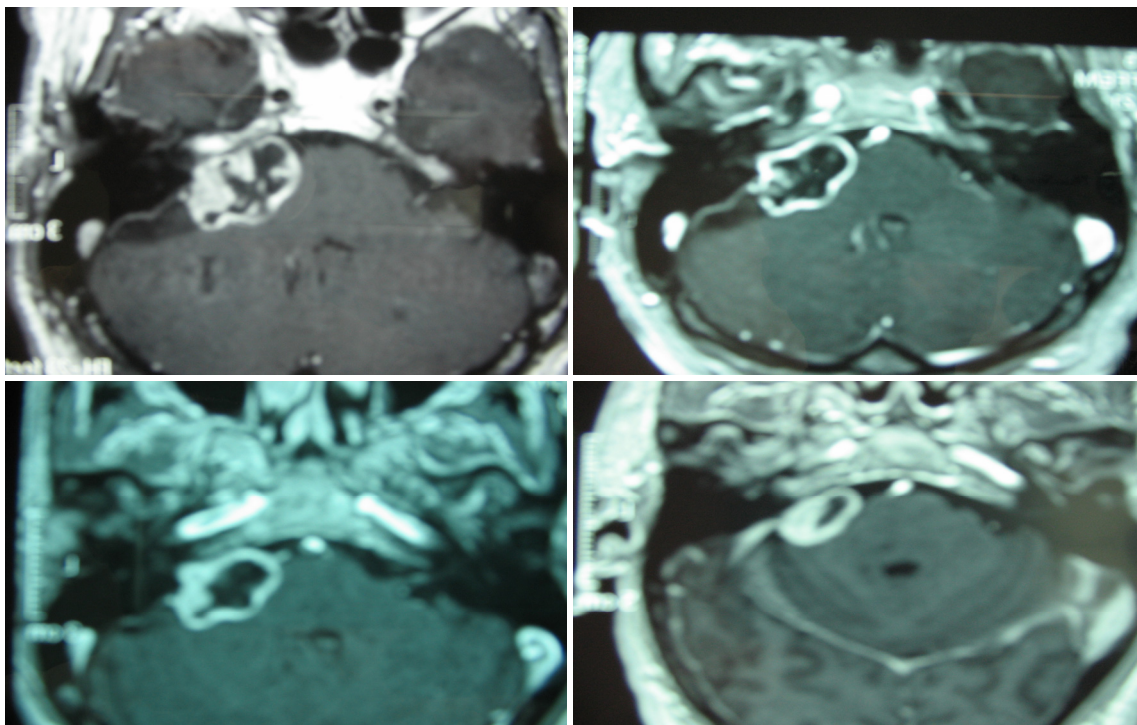Right: control at 6 months (central necrosis)

Figure 2 Upper left: Male, 73 yrs., before therapy. Dose 11 Gy, tumor volume 5.6 cm³.
At 24 months after gamma-knife tumor volume 3,1 cm³ (lower right). Dimensions before therapy:
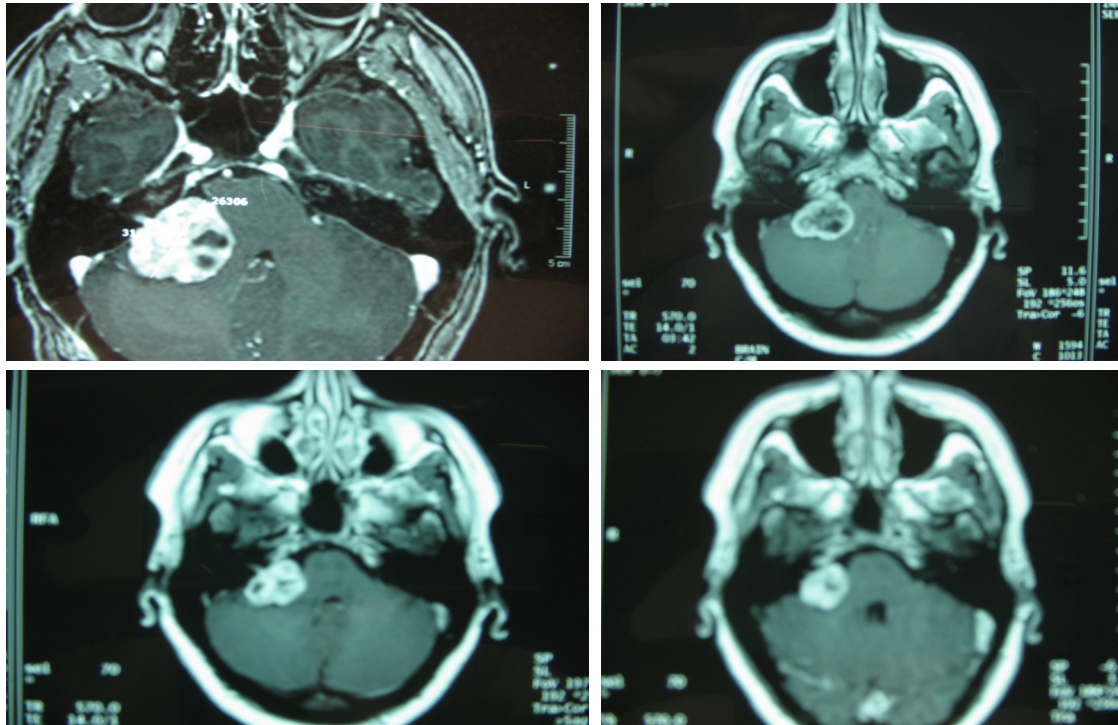3 cm x 2 cm, and after therapy: 2 cm x 1,4 cm.

Figure 3 Female, 44 yrs., before therapy. Dose 11 Gy (50%). After 6, 12, and 24 months respectively. Tumor volume before therapy 12,4 cm^3, 24 months after therapy 3cm^3.

Larson et al. proposed the use of a single dose of 13.5 Gy, given the biological effect of delayed tissue response. Flickinger and ass. have questioned whether or not the tumor control rate could be reduced by a dose smaller than 13 Gy. In this study, we had satisfactory results in patients treated with a median marginal dose of 12.09 Gy (11-14 Gy). Thus, in our experience it is possible to obtain satisfactory long-term control of the tumor at a marginal dose less than 11 Gy. Tumor control rate was in no way worse than those reported in earlier series, where significantly higher doses were used.

Optimal dosage for preservation of cranial nerves

It has been suggested that the facial nerve tolerates marginal doses up to 15 Gy, but doses above 14 Gy have been shown to lead to a significant increase in neuropathy incidence, particularly in the patients with large tumors. In the early days of radiosurgery, subjective numbness or hypoesthesia has been reported as major complication of trigeminal nerve radiation damage. The incidence was as high as 19% in both Karolinska and Pittsburgh series. The large tumoral volume and high radiation doses used corroborate to this undesirable consequence of radiation therapy. The incidence of trigeminal neuropathy was reduced to 4% transient neuropathy and 1.6% persistent neuropathy in Charlottesville exerience, where the average marginal dose used was 13.2 Gy. In the present series, no patient developed any kind of sensory deficit. Preservation of hearing has become the main concern in advanced radiosurgery. In this study, 43 of 60 patients with good preoperative hearing, maintain a functional hearing during a

follow-up period of 21 months. Numerous studies have reported a total rate of 33-55% of hearing preservation in a 2-4 years period after treatment. A definite inverse correlation exists between the dimensions of the tumor and the probability of hearing preservation. Prasad and colleagues have reported a marginal inverse correlation between the dose used and the likelihood of hearing preservation, especially manifest at a dose higher than 13 Gy. In our series, neither the volume of the tumor nor the marginal dose appear to play a critical role in postoperative hearing preservation. In contrast, pure tone audiometry before Gamma Knife surgery seems to be a good possible measure for evaluating the results.

Loss of central contrast enhance

Loss of central enhancing on MRI imaging was observed in 54% of patients of Prasad et al., 70% of Nóren, et al. and 63% of Flickinger, et al series. In this study, this phenomenon was observed in 63.3% of cases. This is a common observation after radiosurgery. More research is required to clarify the pathogenesis. Backlund reported that tumor necrosis was found in a histological study, which corresponds to the central region of enhanced MRI image. Seo, et al. showed using scanning with 99Tc (human serum albumin - dietulenetriamin pentaacetic acid-photon) positron emission computed tomography reduced vascularization of vestibular schwannoma 1 to 2 years after radiosurgery,. Spiegelman and colleagues have suggested that ischemia was produced by tumor associated acute edema. Fukoka and colleagues suggested that apoptosis may be a possible mechanism. Based on these observations, it is aceeptable to consider that the loss of radiological central enhancing is a reliable indicator of long-term good control. This hypothesis, however, requires additional data from more patients and longer-term follow-up.

Failed treatment

In no case was there any evidence of active tumor growth. It has to be considered that labyrinth schwanomas can swell without regrowing after radiosurgery. It is suggested that the modest doses currently in use may reduce this tendency.

Conclusions

Using small doses of radiation (similar to those used in the reference series from Karolinska and Pittsburg, smaller than the usual doses used in other gamma-knife units) can control the volume of the lesion as shown by the follow-up controls results.

Stereotactic MRI and a multiple dosage program seem to be the main factors in achieving this result. According to published results the method can fail if the doctor decides not to partially exclude the lesions localized ar superior limit of the treated region.

References

1. Andrews JC, Wackym PA, Canalis RF: Translabyrinthine approach to the cerebellopontine angle and internal auditory canal. In Samii M, Cheatham M, Becker DP (eds): Atlas of Cranial Base Surgery. Philadelphia, WB Saunders, 1995, pp 18-23.
2. Atkinson WJ: Anterior inferior cerebellar artery. J Neurol Neurosurg Psychiatry 12:137-151, 1949.
3. Backlund EO: Stereotactic radiosurgery in intracranial tumors and vascular malformations. Adv Tech Stand Neurosurg 6:3–37, 1979.
4. Burger PC, Scheithauer BW, Vogel FS: Surgical Pathology of the Nervous System and Its Coverings. New York, Churchill Livingstone, 1991.
5. Cairns H: Acoustic neurinoma of the right cerebellopontine angle: Complete removal. Spontaneous recovery from postoperative facial palsy. Proc R Soc Med 25:7-12, 1931.
6. Cerullo LJ, Grutsch JF, Heiferman K, Osterdock R: The preservation of hearing and facial nerve function in a consecutive series of unilateral vestibular nerve

schwannoma surgical patients (acoustic neuroma). Surg Neurol 39:485-493, 1993.

7. Chung WY, Pan HC, Guo WY, et al: Protection of visual pathway in Gamma knife radiosurgery for craniopharyngiomas. Stereotact Funct Neurosurg 70 (Suppl 1):139–151, 1998.

8. Cross JP: Unilateral neurilemmomas of the VII-th cranial nerve: Then and now. Am J Otol 3:28-34, 1981.

9. Cushing H: Tumors of the Nervus Acusticus and the Syndrome of the Cerebellopontine Angle. Philadelphia, WB Saunders, 1917.

10. Dandy WE: An operation for the total removal of cerebellopontine (acoustic) tumors. Surg Gynecol Obstet 1:129-148, 1925. 38

11. Dandy WE: Removal of cerebellopontine (acoustic) tumors through a unilateral approach. Arch Surg 29:337-344, 1934.

12. Dandy WE: Results of removal of acoustic tumors by the unilateral approach. Arch Surg 42:1026-1033, 1941.

13. DituUio MV, Malkasian D, Rand RW: A critical comparison of neurosurgical and otolaryngological approaches to acoustic neuromas. J Neurosurg 48:1-12,1978.

14. Ebersold MJ, Hamer SG, Beatty CW, et al: Current results of the retrosigmoid approach to acoustic neurinoma. J Neurosurg 76:901-909, 1992.

15. Fischer G, Fischer C, Remond J: Hearing preservation in acoustic neurinoma surgery. J Neurosurg 76:910-917, 1992.

16. Flickinger JC, Kondziolka D, Lunsford LD: Dose and diameter relationships for facial, trigeminal, and acoustic neuropathies following acoustic neuroma radiosurgery. Radiother Oncol 41: 215–219, 1996.

17. Flickinger JC, Kondziolka D, Niranjan A, et al: Results of acoustic neuroma radiosurgery: an analysis of 5 years, experience using current methods. J Neurosurg 94:1–6, 2001.

18. Foster DMC, Kemeny AA, Pathak, et al: Radiosurgery: a minimally interventional alternative to microsurgery in the management of acoustic neuroma. Br J Neurosurg 10:169–174, 1996.

19. Fukuoka S, Oka K, Seo Y, et al: Apoptosis following gamma knife radiosurgery in a case of acoustic schwannoma. Stereotact Funct Neurosurg 70 (Suppl 1):88–94, 1998.

20. Gantz BJ, Wackym PA: Facial nerve abnormalities. In Bumstead R, Smith J (eds): Pediatric Facial Plastic and Reconstructive Surgery. New York, Raven Press, 1993, pp 337-347.

21. Gardner G, Robertson JH: Hearing preservation in unilateral acoustic neuroma surgery. Ann Otol Rhinol Laryngol 97:55–66, 1988.

22. Glasscock ME, Poe DS, Johnson GD: Hearing preservation in surgery of cerebellopontine angle tumors. In Fisch U, Valavanis A, Yasargil M (eds): Proceedings of the Sixth International Symposium of Neurological Surgery of the Ear and Skull Base. Zurich, Kugler & Ghediru, 1988, pp 207-216.

23. Hardy RWJ, Kinney SE, Lueders H, Lesser RP: Preservation of cochlear nerve function with aid of brain stem auditory evoked Potentials. Neurosurgery 11:16-19, 1982.

24. Horrax G, Poppen JL: Experiences with the total and intracapsular extirpation of acoustic neuromata. Ann Surg 110:513-524, 1939.

25. Horrax G: A comparison of results after intracapsular enucleation and total extirpation of acoustic tumors. J Neurol Neurosurg Psychiatry 13:268-270, 1950.

26. House JW, Brackmann DE: Facial nerve grading system. Otololaryngol Head Neck Surg 93:146–147, 1985.

27. House WF, Hitselberger WE: Fatalities in Acoustic Tumor Surgery, vol 2. Baltimore, University Park Press, 1979, pp 235-264.

28. House WF: Case summaries. Arch Otolaryngol 88:586-591, 1968.

29. House WF: Monograph I: Transtemporal bone microsurgical removal of acoustic neuromas. Arch Otolaryngol 80:587-756, 1964.

30. House WF: Monograph II: Acoustic neuroma. Arch Otolaryngol 88:576-715, 1968.

31. House WF: Trarislabyrinthine Approach, vol 2. Baltimore, University Park Press, 1979, pp 43-87, 12:137-151, 1949.

32. Jackler RK, Brackmann DE (eds): Neurotology. St. Louis, Mosby- Year Book, 1994.

33. Jenkins HA: Hearing preservation in acoustic neuroma surgery. Laryngoscope 102:125-128, 1992.

34. Kanzaki I, Kunihiro T, O-Uchi T, et al: Preservation of facial I nerve function in acoustic neuroma surgery by extended middle fossa approach. Acta Otolaryngol Suppl 487:36-40, 1991.

35. Kanzaki J, OUchi T, Shiobara R, Toya S: Hearing preservation in acoustic neuroma surgery by the extended middle fossa method. Otolaryngol Suppl Acta 487:22-29, 1991.

36. Kaplan EL, Meier P: Nonparametric estimation from incomplete observations. J Am Stat Assoc 53:457–481, 1958.

37. Kartush JM, Lundy LB: Facial nerve outcome in acoustic neuroma surgery. Oaolaryngol Clin North Am 25:623-647, 1992.

38. Kondziolka D, Lunsford LD, McLaughlin MR, et al: Long-term outcomes after radiosurgery for acoustic neuromas. N Engl J Med 339:1426–1433, 1998.

39. Kwartler JA, Luxford WM, Atkins J, Shelton C: Facial nerve monitoring in acoustic neuroma surgery. Otolaryngol Head Neck Surg 104:814-517, 1991.

40. Lalvvani AK, Butt FY, Jackler RK, et al: Facial nerve outcome after acoustic neuroma surgery: A study from the era of cranial nerve monitoring. Otolaryngol Head Neck Surg 111:561-570, 1994.

41. LaRouere MJ, Niparko JK, Gebarski SS, Kemink JL: Three-dimensional x-ray computed tomography of the temporal bone as an aid to surgical planning. Otolaryngol Head Neck Surg 103:740-747, 1990.

42. Larson DA, Flickinger JC, Loeffler JS: The radiobiology of radiosurgery. Int J Radiat Oncol Biol Phys 25:557–561, 1993.

43. Linskey ME, Lunsford LD, Flickinger JC: Neuroimaging of acoustic nerve sheath tumors after stereotactic radiosurgery. AJNR Am J Neuroradiol 12:1165-1175.1991.

44. Linskey ME, Lunsford LD, Flickinger JC: Neuroimaging of acoustic nerve sheath tumors after stereotaxic radiosurgery. AJNR Am J Neuroradiol 12:1165–1175, 1991.

45. Linskey ME, Lunsford LD, Flickinger JC: Radiosurgery for acoustic neurinoma: early experience. Neurosurgery 26: 736–745, 1990.

46. List CF: Die operative behandling die acoustic neurinoma mit drei ergebrisse. Arch U Klin Chir 171:282-325, 1932.

47. Lunsford LD, Kamerer DB, Møller M: Gamma knife: an alternative treatment for acoustic neurinomas. Ann Otol Rhinol Laryngol 97:631–635, 1988.

48. Lye RH, Dutton J, Ramsden RT: Facial nerve preservation during surgery for removal of acoustic nerve tumors. J Neurosurg 57:739-743, 1982.

49. Mafee MF, Kumar A, Valvassori GE, et al: Diagnostic potential of CT in neurological disorders. Laryngoscope 95:505-514,1985.

50. McKenzie KG, Alexander EJ: Acoustic neuroma. Clin Neurosurg 2:21-36, 1955.

51. Moller AR, Janetta PJ: Preservation of facial function during removal of acoustic neuromas. J Neurosurg 61:757-760, 1984.

52. Mrazek J, Fisur Z, Mazkora D: Diagnosis, size, and operation results in 41 acoustic neurinomas. Neoplasma 35:467-474, 1988.

53. Nedzelski JM, Tatar CH: Hearing preservation: A realistic goal in surgical removal of cerebellopontine angle tumors. J Otolaryngol 13:355-360, 1984.

54. Neely JG: Hearing conservation surgery for acoustic tumors: A clinical-pathologic correlative study. Am J Otol 6:143-146, 1985.

55. Neely JG: Is it possible to totally resect an acoustic tumor and conserve hearing? Otolaryngol Head Neck Surg 92:162-167, 1984.

56. Norén G, Arndt J, Hindmarsh T: Stereotactic radiosurgery in cases of acoustic neurinoma: further experiences. Neurosurgery 13: 12–22, 1983.

57. Norén G, Greitz D, Hirsh A, et al: Gamma knife radiosurgery in acoustic tumors. Acta Neurochir Suppl 58:104–107, 1993.

58. Norén G: Gamma knife radiosurgery in acoustic neuromas, in Haid C (ed): Vestibular Diagnoses and Neurootological Management of the Skull Base. Gräfelfing: Demeter Verlag, pp 43–45, 1991.

59. Ogunrinde OK, Lunsford LD, Kondziolka, et al: Cranial nerve preservation after stereotactic radiosurgery of intracanalicular acoustic tumors. Stereotactic Funct Neurosurg 64 (Suppl 1): 87–97, 1995.

60. Olivecrona H: Acoustic tumors. J Neurosurg 26:6-13, 1967.

61. Olivecrona H: Analysis of results of complete and partial removal of acoustic neuromas. J Neurol Neurosurg Psychiatry 13: 271-272, 1950.

62. Poole JL, Pava AA: The Early Diagnosis and Treatment of Acoustic Nerve Tumors. Springfield, IL, Charles C Thomas, 1957.

63. Poole JL: Suboccipital surgery for acoustic neurinomas: Advantages and disadvantages. J Neurosurg 24:483-492, 1966.

64. Post K, Eisenberg MB, Catalano PJ: Hearing preservation in vestibular schwannoma surgery: What factors influence outcome? J Neurosurg 83:191-196, 1995.

65. Prasad D, Steiner M, Steiner L: Gamma surgery for vestibular schwannoma. J Neurosurg 92:745–759, 2000.

66. Prasad S, Hirsch BE, Kamerer DB, et al: Facial nerve function following cerebellopontine angle surgery: Prognostic value of intraoperative thresholds Am J Otol 14:330-333, 1993.

67. Rand RW, Kurze T: Case reports and technical notes: Preservation of vestibular, cochlear and facial nerves during microsurgical removal of acoustic tumors—report of two cases. J Neurosurg 28:158-161, 1968.

68. Rand RW: Microneurosurgery for acoustic tumors. In Microneu rosurgery. St. Louis, CV Mosby, 1969, pp 126-155.

69. Samii M, Matthies C: Management of 1000 vestibular schwannomas (acoustic neuromas): Hearing function in 1000 tumor resections. Neurosurgery 40:248-260, 1997.

70. Samii M, Matthies C: Management of 1000 vestibular schwannomas (acoustic neuromas): The facial nerve-preservation and restitution of function. Neurosurgery 40:684-694, 1997.

71. Samii M, Matthies C: Management of 1000 vestibular schwannomas (acoustic neuromas): Surgical management and results with emphasis on complications and how to avoid them. Neurosurgery 40:11-21, 1997.

72. Samii M, Matthies C: Management of 1000 vestibular schwannomas (acoustic neuromas): surgical management and results with an emphasis on complications and how to avoid them. Neurosurgery 40:11–23, 1997.

73. Sampath P, Holliday MJ, Brem H, et al: Facial nerve injury in acoustic neuroma (vestibular schwannoma) surgery: Etiology and prevention. J Neurosurg 87:60-66, 1997.

74. Sampath P, Holliday MJ, Brem H, et al: Facial nerve injury in acoustic neuroma (vestibular schwannomas) surgery: etiology and preservation. J Neurosurg 87:60–66, 1997.

75. Sampath P, Holliday MJ, Brem H, et al: PrevenHon of facial nerve injury in vestibular schwannoma surgery. Neurosurg Focus 5:4, 1998.

76. Sampath P, Rhines LD, Goel R, Long DM: Cranial nerve preservation in vestibular schwannoma (acoustic neuroma) surgery. Crit Rev Neurosurg 8:86-96, 1998.

77. Selesnick SH, Jacker RK: The changing clinical presentation of acoustic tumors in the MRI era. Laryngoscope 103:431–436, 1993.

78. Seo Y, Fukuoka S, Nakagawara J, et al: Effect of gamma knife radiosurgery on acoustic neurinomas. Assessment by 99mTc- DPTA-human serum albumin- and 201TlCl-single photon emission computed tomography. Stereotact Funct Neurosurg 66 (Suppl 1): 93–102, 1997.

79. Spiegelmann R, Lidar Z, Gofman J, et al: Linear accelerator radiosurgery for vestibular schwannoma. J Neurosurg 94:7–13, 2001.

80. Sterkers JM, Morrison GA, Sterkers O, Badr El-Dine MMK: Preservation of facial, cochlear, and other nerve functions in acoustic neuroma treatment. Otolaryngol Head Neck Surg 110:146-155, 1995.

81. Sterkers JM, Morrison GA, Sterkers O, El-Dine MM: Preservation of facial, cochlear, and other nerve functions in acoustic neuroma treatment. Otolaryngol Head Neck Surg 110:146-155, 1994.

82. Tator CH, Nedzelski JM: PreservaHon of hearing in patients undergoing excision of acoustic tumors and other cerebellopon tine angle tumors. J Neurosurg 63:168-174, 1985.

83. Tos M, Thomsen J: Ten years' experience with translabyrinthine acoustic neuroma surgery in Denmark. Acta Otolaryngol Suppl 449:2S-24, 1988.

84. Varlotto JM, Shrieve DS, Alexander E III, et al: Fractionated stereotactic radiotherapy for the treatment of acoustic neuromas: preliminary results. Int J Radiat Oncol Biol Phys 36:141–145, 1996.

85. Wackym PA, Andrews JC: Middle cranial fossa approach. In Samii M, Cheatham M Becker DP (eds): Atlas of Cranial Base Surgery. Philadelphia, WB Saunders, 1995, pp 26-31.

86. Wackym PA, Linthicum FH Jr: Diabetes mellitus and hearing loss: Clinical and histopathological relationships. Am J Otol 7: 176-182, 1986.

87. Wackym PA, Rice DH, Schaefer SD (eds): Minimally Invasive Surgery of the Head, Neck, and Cranial Base. Philadelphia, Lippincott Williams & Wilkins, 2002, pp 1-559.

88. Whittaker CK, Luetje CM: Vestibular schwannomas. J Neuro surg 76:897-900, 1992.

89. Yasargil MG, Fox JL: The microsurgical approach to acoustic neurinomas. Surg Neurol 2:393-398, 1974.

90. Yasargil MG, Smith RD, Gasser JC: Microsurgical approach to acoustic neurinomas. Adv Tech Stand Neurosurg 4:93-197, 1977.

91. Yasargil MG: A legacy of microneurosurgery: Memoirs, lessons, and axioms. Neurosurgery 45:1025-1091, 1999.