Glomus jugulare tumors arise from the paraganglia of the chemoreceptor system and occur in intra- and extra-cranial locations. Local invasion of adjacent structures or the effect of the tumor mass causes symptoms. Neurovascular structures within the hypoglossal canal, jugular foramen, and temporal bone can be affected. Treatment has included resection, embolization, external-beam radiation therapy, or a combination of these modalities.6

Surgery has been performed most frequently in young patients or in those with complete loss of cranial nerve function. To decrease the morbidity associated with tumor management in these patients, gamma knife surgery (GKS) was performed as an alternative to resection.

Methods. Between 1990 and 2003, 42 patients underwent GKS as the primary management (19 patients) or for recurrent glomus jugulare tumors (23 patients). Facial weakness and deafness were more common in patients with recurrent tumors than in those in whom primary GKS was performed (48% compared with 11%, p = 0.02). The mean tumor volume was 13.2 cm³; the mean tumor margin dose was 14.9 Gy. The mean follow-up period for the 39 patients in whom evaluation was possible was 44 months (range 6–149 months). After GKS, 12 tumors (31%) decreased in size, 26 (67%) were unchanged, and one (2%) grew. The patient whose tumor grew underwent repeated GKS.

Progression-free survival after GKS was 100% at 3 and 7 years, and 75% at 10 years. Six patients (15%) experienced new deficits (hearing loss alone in three, facial numbness and hearing loss in one, vocal cord paralysis and hearing loss in one, and temporary imbalance and/or vertigo in one). In 26 patients in whom hearing could be tested before GKS, hearing preservation was achieved in 86 and 81% at 1 and 4 years posttreatment, respectively. No patient suffered a new lower cranial nerve deficit after one GKS session; the patient in whom repeated GKS was performed experienced a new vocal cord paralysis 1 year after his second procedure.

Conclusions. Gamma knife surgery provided tumor control with a low risk of new cranial nerve injury in early follow-up review. This procedure can be safely used as a primary management tool in patients with glomus jugulare tumors that do not have significant cervical extension, or in patients with recurrent tumors in this location.

Key Words • glomus jugulare tumor • jugular foramen • gamma knife surgery

Abbreviations used in this paper: GKS = gamma knife surgery; MR = magnetic resonance.
The patient characteristics are outlined in Table 1. Of note, patients in whom primary GKS was performed were older (mean age 66.7 years compared with 51.8 years, p < 0.01). Patients who underwent prior surgery were more likely to experience facial weakness and to be deaf (48% compared with 11%, p = 0.02 in both instances).

**Radiosurgical Dosimetry**

Radiosurgery was performed using the Leksell Gamma Knife (Elekta Instruments, Norcross, GA) Model U was used before March 1997, and thereafter, the procedure was performed using model B. Stereotactic MR imaging was the modality used for dose planning in 41 patients; in the other one planning was aided by cerebral angiography. Multiple-shot dose plans were created to cover conformally the often irregularly shaped tumors. The mean number of isocenters used was 8.3 (range 3–15). Thirty-two patients (76%) were treated at the 50% isodose line, one was treated at the 45% isodose line, and nine were treated at the 40% isodose line. The median prescription isodose volume was 13.2 cm³ (range 1.2–32.2 cm³). The mean tumor margin dose was 14.9 Gy (range 12–18 Gy). The mean maximum tumor dose was 31.2 Gy (range 24–37.5 Gy). There was no difference in the number of isocenters, tumor volume, and minimum or maximum radiation doses between the group of patients who had undergone previous surgery and the group undergoing primary GKS.

**Follow-Up Review**

Gamma knife surgery has been performed as an outpatient procedure since 1997. After GKS, all patients underwent follow-up evaluation and neuroimaging performed at 6, 12, 24, and 48 months, then twice a year after GKS. The tumor diameter was ascertained in the x, y, and z planes and compared with studies obtained on the day GKS was performed. Tumor size was classified as unchanged, decreased, or increased. Tumor reduction was considered progression. Tumors with less than a 2-mm reduction were labeled as unchanged. In addition, the follow-up MR images were reviewed for evidence of adverse radiation-related effects.

Thirty-nine patients were treated more than 6 months ago and have been prospectively followed. No patient has been lost to follow-up review. The mean follow-up duration after GKS was 44 months (range 6–149 months).

**RESULTS**

After GKS 12 tumors (31%) shrunk (Fig. 1), 26 (67%) were unchanged, and one tumor (2%) enlarged. No correlation was found between tumor shrinkage and tumor margin dose (p = 0.55), maximum radiation dose (p = 0.4), or length of follow up (p = 0.66). The patient with tumor growth initially presented with lower cranial nerve deficits and underwent primary GKS for a lesion measuring 39 mm in its largest dimension (Fig. 2). The prescription isodose volume was 29.7 cm³. The tumor margin dose was 12 Gy and the maximum dose was 24 Gy. Ninety-nine months after radiosurgery, this patient experienced hearing loss, and repeated MR imaging revealed that the tumor was larger. The patient underwent repeated GKS because of his advanced age (76 years). The volume covered was 50.3 cm³, the tumor margin dose was 14 Gy, and the maximum dose was 35 Gy. One year after the repeated procedure the patient experienced a vocal cord paralysis, but he has not required any additional surgery to manage this complication. Follow-up MR imaging demonstrated that the tumor was unchanged in size, but edema was observed in the adjacent cerebellum. Three patients died of unrelated causes after GKS. The progression-free survival rate after GKS was 100% at 3 and 7 years, and 75% at 10 years (Fig. 3).

**Posttreatment Complications**

In addition to the patient with hearing loss and vocal cord paralysis described earlier, five others had complications related to the procedure. One patient had persistent headache, nausea, and vomiting in the days after GKS and required a short course of antiemetic and corticosteroid medications. One patient had increased imbalance and vertigo 9 months post-GKS, but the symptoms improved with vestibular training. One patient experienced decreased facial sensation 6 months after GKS.

The most common complication was hearing loss. Overall, five (19%) of 26 patients with intact hearing before GKS had a subjective decline in hearing after the operation. Hearing preservation was achieved in 86 and 81% at 1 and 4 years, respectively (Fig. 4). One patient with a hormone-secreting tumor attained normal biochemical status 42 months post-GKS. The remaining patients (82%) remained stable or improved subjectively after GKS.

**DISCUSSION**

The management goals for glomus jugulare tumors must take two facts into consideration. One is that, although malignant paragangliomas do occur, the majority of patients have benign tumors that grow very slowly. In fact, patients have been reported who have survived more than 40 years with no treatment. The other fact is that the...
functional consequences of a lower cranial nerve injury are far more significant than injury to other cranial nerves. Ojemann\textsuperscript{14} stated in an editorial on skull base surgery that if the patient has a high probability of being cured of the tumor or of having a useful life significantly lengthened or more serious disabilities relieved, then the loss of facial nerve function or hearing is acceptable. On the other hand, the loss of ninth and 10th cranial nerve function is one of the most serious neurological disabilities for a patient. There is a real question as to whether one should electively give this disability to a patient.\textsuperscript{14} A paper by Netterville and Civantos\textsuperscript{13} on rehabilitation from glossopharyngeal, vagus, and accessory nerve deficits after neurootological skull base surgery affirmed the significance of such deficits. They said that “. . . the time required to return to a reasonably enjoyable diet often extends to one year postoperatively. A few never attain the goal of enjoyable intake and continue to struggle to maintain adequate nutrition. The latter situation is the rule, not the exception, in the elderly population.” Steinberg and Holz\textsuperscript{17} also discuss this problem. Consequently, the ideal treatment for these patients should provide protection from tumor progression and a minimal chance of injury to the lower cranial nerves.

In our experience, GKS is effective in patients with glomus jugulare tumors. At a follow-up interval that extended more than 12 years for some patients, only one had tumor progression. The time to treatment failure in that patient was 99 months. Based on this case, it could be argued that GKS may slow the growth of these tumors, but after an interval they will again become active and begin to enlarge. This same argument has been advanced regarding the use of fractionated radiation therapy for glomus jugulare tumors.\textsuperscript{1} Nevertheless, almost one third of our patients had a reduction in tumor size after GKS.

Another criticism could be that for patients in whom there was no reduction in tumor size after GKS, we are simply seeing the natural history of these tumors, which may remain quiescent for decades even without treatment. Nevertheless, in 23 (59\%) of 39 patients in whom evaluation was possible, tumor growth was documented on serial imaging before GKS was performed.

It should be noted that the tumor margin dose for our patient who failed GKS was 12 Gy. Therefore, higher radiation doses to the tumor margin may be required to provide long-term growth control. We intend to follow patients closely when they undergo GKS for benign tumors so that we can clearly define the success of this procedure, and we will evaluate whether reduced doses are associated with higher rates of tumor progression at extended follow-up intervals.\textsuperscript{8} An extended follow-up period is also necessary to understand better the incidence of radiation-induced neoplasms after GKS.\textsuperscript{12}

Gamma knife surgery has been proven to be safe for patients with glomus jugulare tumors. New permanent neurological deficits occurred in only five (13\%) of 39 patients; the most common complication was hearing loss. In our patients, the actuarial rate of hearing preservation exceeded 80\% 4 years post-GKS. The most likely explanation for hearing loss is not radiation injury to the vestibulocochlear nerve, but rather radiation injury to the cochlea and other temporal bone structures.\textsuperscript{10} Support for this concept comes from the fact that no patient suffered a facial weakness in our series. Increased awareness of the possibility of hearing decline related to temporal bone radiation exposure may increase the rate of hearing preservation in these patients. Nonetheless, in some patients tumors are intimately involved with the hearing apparatus and sparing these structures may not be possible if complete radiation coverage of the tumor is desired.
Perhaps the most significant finding has been that the risk of lower cranial nerve injury is quite low. In our experience with patients who have glomus jugulare tumors and other lesions located in and around the jugular foramen, none has suffered a lower cranial nerve deficit after a single session of GKS. The patient in our series who underwent two procedures experienced vocal cord paralysis 1 year after repeated GKS. As a result, we believe that it is...
Glomus jugulare gamma knife surgery

possible that even cranial nerves thought to be relatively resistant to injury from radiation can be affected by repeated, high-dose exposures.

CONCLUSIONS

Gamma knife surgery provided tumor control with a low risk of new cranial nerve injury according to early follow-up evaluations. Radiosurgery can be safely used as a primary management tool in patients with glomus jugulare tumors that do not have significant cervical extension, or in patients who have recurrent tumors in this location.

References


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