Single-session image-guided robotic radiosurgery and quality of life for glomus jugulare tumors

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Abstract
Background: Limited data are available on the efficacy and impact on the quality of life (Qol) of single-session image-guided robotic radiosurgery (RRS) for glomus jugulare tumors (GJTs). This study investigates the role of RRS in the management of GJTs and reviews the RRS literature.

Methods: We analyzed 53 GJT patients treated with RRS to evaluate the safety, local control, clinical outcome, and Qol assessed by the SF12v2.

Results: The local control was 98% at a median follow-up of 38 months. The median tumor volume was 4.3 cc and tumors were treated with a median dose of 16.5 Gy. At the last follow-up, 35 patients had recovered from their symptoms or experienced symptom improvement. Qol analyses showed no significant decline while bodily pain significantly decreased.

Conclusions: RRS is a safe and efficient tool for the treatment of GJTs. Qol of patients after treatment is stable and tends to improve over time.

Key words: CyberKnife, glomus jugulare, quality of life, radiosurgery, review

1 | INTRODUCTION

Paragangliomas, also known as chemodectomas, are highly vascularized, rare, slow-growing tumors deriving from extra-adrenal parasympathetic or sympathetic paraganglia. Depending on their location, size, and hormone activity, they can cause a broad spectrum of symptoms ranging from pulsatile tinnitus, headache, hearing loss, vertigo, and lower cranial nerve palsies in glomus jugulare tumors (GJTs) to tachycardia and labile blood pressure in catecholamine-secreting paragangliomas. Even though histologically considered as benign tumors, paragangliomas can locally infiltrate surrounding tissue such as bones or vessels. Moreover, tumors can metastasize, leading to a significantly decreased overall survival rate. However, only approximately 3% of the found tumors are considered to be malignant, bearing the risk of distant metastases.

Until the development of radiotherapy, the primary treatment option for paragangliomas was the surgical resection of the tumor. Due to its high vascularization and its localization near the skull base and large vessels, surgical procedures may cause severe complications including high-grade cranial nerve dysfunctions, significant blood loss, and strokes. Despite technical advancements, the microsurgical...
tumor extirpation yields substantial morbidity for patients, also when preoperative embolization procedures are performed to reduce the intraoperative bleeding risk.8,9

Today, possible treatment options range from surgery alone, tumor embolization with and without surgical resection to various radiation techniques including fractionated radiotherapy, proton therapy as well as radiosurgery.10-15 There is still no consensus on the optimal management in regard to local tumor control, treatment-related morbidity, and quality of life (Qol).16 However, since its introduction, primary and adjuvant radiotherapy played a pivotal role in the management of glomus jugulare patients, showing similar or even better treatment outcomes than surgical approaches.8,17

Several studies have investigated the role of radiosurgery in the treatment of GJTs either using single-session or fractionated treatments.18 Especially the use of Gamma Knife (GK)- and linear accelerator-based radiosurgery were analyzed by different researchers over the past decades and showed good results.17,19-22 Due to the inherent limitations of the stereotactic frame-based radiosurgery, it may not be performed for lower located GJTs. Image-guided robotic radiosurgery (RRS) has no such spatial limitation. Moreover, only sparse data are available on the role of RRS for the management of GJTs.

Furthermore, almost no data are available on post-treatment Qol changes in this tumor entity.

The aim of this retrospective, monocentric study is to report and evaluate the efficacy and safety of RRS and its impact on the posttreatment Qol at our institution. Finally, we compare our results with the existing RRS literature.

2 | MATERIALS AND METHODS

2.1 | Patients

Fifty-three patients with GJTs were consecutively treated between July 2005 and November 2018 and enrolled in this retrospective, monocentric study. Medical history, previous treatments, clinical symptoms as well as treatment and follow-up data were collected in a dedicated database for radiosurgery. Local tumor response, clinical symptoms, and adverse events were evaluated clinically and by MRI assessment every 6 months for the first year after treatment and then every 12 to 24 months for the following years. This study received the approval of the institutional review board. Informed and written consent was obtained from all patients prior to data assessment, evaluation, and analysis.

2.2 | Treatment procedure and outcome

Prior to RRS, patients underwent a planning CT scan and MRI of the head, both with 1-mm slice thickness and contrast agent. The CT was subsequently overlaid with secondary MRI, including gadolinium-enhanced T1 and T2 sequences, as well as vessel-focused time of flight series when available. Inverse treatment planning was performed with various versions of the MultiPlan and Precision software (MultiPlan, Precision, Accuray Inc, Sunnyvale, California). All treatments were delivered in a single-session outpatient setting using a CyberKnife RRS system (Accuray Inc). The CyberKnife utilizes a lightweight 6 MeV linear accelerator mounted on a six-axis robotic arm, a stereoscopic kV imaging system, and a robotic treatment table. In all patients, the 6D-Skull tracking software was used to track the position of the patient’s head, whereas custom-fitted thermoplastic face masks were employed for light, noninvasive fixation.23 Radiographic assessment of the treatment outcome was defined as follows. Complete remission (CR) is the disappearance of the whole tumor, partial response (PR) is at least a 30% decrease in tumor volume, minor response is a decrease of tumor volume up to 30%, stable disease is the unchanged tumor volume, and progressive disease (PD) is an increase of the overall tumor volume of at least 20% or tumor growth of at least 5 mm. Local control (LC) was defined as no radiographic evidence of PD.

2.3 | Quality of life

Health-related Qol was assessed using the 12-item health survey questionnaire (SF12v2, 1992, 2000 Health Assessment Lab, Medical Outcomes Trust and QualityMetric Inc). The SF12v2 assesses various health concepts (HC) of Qol including physical functioning (PF), role physical (RP), bodily pain (BP), general health, vitality (VT), social functioning (SF), role emotional, and mental health (MH).

Patients were asked to complete the questionnaire before treatment delivery and during follow-up visits. All survey results were evaluated using the SF Health Outcomes Scoring Software (Qualimetric Inc, Lincoln, Rhode Island). Only patients who answered all questions were included in the analysis. The received answers were transformed into a standardized continuous scale ranging from 0 to 100, with 50 being the mean. Higher SF12v2 scores indicate a better Qol and better overall function. The data were tested for normality by graphic appearance, skewness, kurtosis, and the Shapiro-Wilk test. Baseline data and values at first and last follow-up were compared using paired two-tailed t tests or Wilcoxon signed-rank tests in STATA 15.1 (StataCorp, College Station, Texas). Statistical significance was set at a P value ≤.05.

2.4 | Literature review

We conducted a PubMed-based literature research by using various keyword combinations including CyberKnife, glomus jugulare tumor, paranganglioma, chemodectoma,
robotic radiosurgery, radiosurgery, radiotherapy, and stereotactic to search the National Library of Medicine database. Only articles that reported the use of single-session or multisession (fractionated) RRS for GJTs or paragangliomas were included in this study, even if they included the treatment of other tumor entities or the use of other radiation techniques. Articles published after February 1, 2019, were not considered.

### TABLE 1  Patient characteristics, pretreatment deficits, and pretreatments

| Patient characteristics | All patients | Untreated | Pretreated |
|-------------------------|--------------|-----------|------------|
| Number of patients      | 53           | 33 (62.3) |            |
| Sex (male/female, %)    | 20 (37.7)    | 33 (62.3) |            |
| Age (years)             | 54.5         | 53.1      | 27.0-83.4  |
| Pretreatment Karnofsky Performance Score (%) | 100 | 95.6 | 80-100 |
| Follow-up (months)      | 38.0         | 46.6      | 4.0-160.8  |
| Number of follow-up MRI scans | 4 | 4.7 | 1-13 |
| Total tumor volume (cc) | 4.3          | 6.3       | 0.1-31.6   |
| Side of the tumor (left/right, %) | 37 (69.8) | 16 (30.2) | -          |
| Dose (Gy)               | 16.5         | 16.2      | 13.5-18.0  |
| Prescription isodose (%)| 70           | 69        | 60-75      |

### Pretreatment deficits

| Pretreatment deficits | All patients | Untreated | Pretreated |
|-----------------------|--------------|-----------|------------|
| Number of patients    | 53           | 33        | 20         |
| Patients without deficits | 3         | 1         | 2          |
| Patients with deficits | 50          | 32        | 18         |
| Pulsatile tinnitus    | 28           | 19        | 9          |
| Partial hearing loss  | 25           | 18        | 7          |
| Dysphagia             | 24           | 14        | 10         |
| Dysarthria            | 19           | 11        | 8          |
| Vertigo               | 15           | 10        | 5          |
| Total hearing loss    | 11           | 4         | 7          |
| Facial nerve palsy (all degrees) | 9 | 1 | 8 |
| Dysesthesia           | 7            | 2         | 5          |
| Feeling of pressure around tumor side | 7 | 7 | 0 |
| Spinal accessory nerve palsy (all degrees) | 5 | 4 | 1 |
| Pain                  | 4            | 3         | 1          |
| Cardiovascular complications | 2 | 2 | 0 |
| Epiphora              | 1            | 1         | 0          |

### Pretreatments

| Pretreatments                                      | Number of patients |
|----------------------------------------------------|--------------------|
| Patients with pretreatments                        | 20                 |
| Single surgery                                     | 9                  |
| Single surgery plus tumor embolization             | 6                  |
| Multiple surgeries                                 | 3                  |
| Multiple surgeries plus tumor embolization         | 1                  |
| Radiosurgery (GK) plus single surgery plus tumor embolization | 1 |

Abbreviations: cc, cubic centimeter; GK, Gamma Knife; Gy, Gray.
### TABLE 2  Radiographic and clinical outcomes of symptomatic patients at the last follow-up

| Radiographic outcomes | CR | PR | MR | SD | PD |
|-----------------------|----|----|----|----|----|
| Number of patients    | 1  | 17 | 10 | 24 | 1  |
| % of all patients     | 1.9| 32.0| 18.8| 45.2| 1.9|
| Crude local control (%) | ~98 | | | | |

| Clinical outcome of symptomatic patients at the last follow-up |
|---------------------------------------------------------------|
| Clinical outcome       | No symptoms | Symptom improvement | Unchanged | Transient worsening | Symptom worsening |
| Number of patients    | 18 | 17 | 13 | 1 | 1 |
| % of all patients     | 33.9| 32.0| 24.5| 1.9| 1.9|

Abbreviations: CR, complete remission; MR, minor response; PD, progressive disease; PR, partial response; SD, stable disease.

### TABLE 3  Qol results (SF12v2)

| Number of patients | 35 |
|--------------------|----|
| Time to first follow-up: |  |
| Median: 6.1 months, mean: 6.7 months |  |
| Mean (±SD) |  |

| HC | Baseline | First follow-up | Δ | P value |
|----|----------|----------------|---|---------|
| PF | 68.5 ± 31.7 | 72.1 ± 34.1 | 3.5 | .23 |
| RP | 64.2 ± 28.7 | 61.0 ± 28.0 | −3.2 | .31 |
| BP | 71.4 ± 30.4 | 77.1 ± 32.3 | 5.7 | .04 |
| GH | 48.8 ± 26.7 | 50.0 ± 27.2 | 1.1 | .78 |
| VT | 52.1 ± 29.3 | 55.7 ± 28.5 | 3.5 | .53 |
| SF | 65.7 ± 28.5 | 68.5 ± 29.9 | 2.8 | .87 |
| RE | 65.7 ± 26.3 | 65.3 ± 28.9 | −0.3 | .80 |
| MH | 59.2 ± 22.5 | 63.9 ± 21.6 | 4.6 | .08 |

| Number of patients | 28 |
|--------------------|----|
| Time to last follow-up |  |
| Median: 38.0 months, mean: 54.5 months |  |
| Mean (±SD) |  |

| HC | Baseline | Last follow-up | Δ | P value |
|----|----------|----------------|---|---------|
| PF | 71.4 ± 30.9 | 73.2 ± 28.0 | 1.7 | .62 |
| RP | 61.1 ± 28.9 | 66.9 ± 26.8 | 5.8 | .06 |
| BP | 72.3 ± 31.4 | 72.3 ± 33.5 | 0.0 | 1.00 |
| GH | 46.4 ± 22.8 | 51.7 ± 25.9 | 5.3 | .18 |
| VT | 53.5 ± 29.4 | 59.8 ± 22.9 | 6.2 | .08 |
| SF | 66.9 ± 28.9 | 72.3 ± 26.6 | 5.3 | .35 |
| RE | 65.1 ± 24.1 | 70.0 ± 21.8 | 4.9 | .41 |
| MH | 61.1 ± 22.4 | 66.9 ± 18.0 | 5.8 | .15 |

Note: All statistically significant values (p < .05) are given in bold.

Abbreviations: BP, bodily pain; GH, general health; HC, health concept; MH, mental health; PF, physical functioning; RE, role emotional; RP, role physical; SF, social functioning; VT, vitality.
3 | RESULTS

3.1 Patient characteristics and treatment parameters

The baseline characteristics of patients are summarized in Table 1. The median age at treatment was 54.5 years, ranging from 27 to 83.4 years. With 33 cases, the majority of patients were female, 20 patients were male. The median tumor volume was 4.3 cc, ranging from 0.1 to 31.6 cc. Most of the treated tumors were located on the left side, with 69.8% vs the remaining 30.2% being on the right side. There were no patients with bilateral tumors. All tumors were treated with RRS using a median dose of 16.5 Gy, enclosing the tumor with doses ranging from 13.5 to 18.0 Gy. The median prescription isodose line was 70%. Fifty patients (94.3%) had pretreatment deficits. The most common symptoms included pulsatile tinnitus, partial hearing loss, dysphagia, dysarthria, and vertigo. The complete list of pretreatment deficits is summarized in Table 1. Overall, 20 patients (37.7%) had received previous treatments with all of them undergoing surgery at least once. Only one patient had received upfront radiosurgery with GK. A detailed overview of the previous treatments is summarized in Table 1.

3.2 Treatment results

All 53 patients obtained a clinical as well as radiographic follow-up which ranged from 4 to 160.8 months with a median of 38 months. The 5-year actuarial LC was 100%, the crude LC was 98% at last follow-up. Fifty-two tumors either shrunk or remained unchanged in size (Table 2). After 70.8 months, one patient developed a local recurrence and was subsequently treated with proton radiotherapy. As of today, there is no new evidence of a local recurrence in this patient. Another patient developed lymph node metastases 4 months after treatment delivery while his primary treatment site remained controlled. During the last follow-up, 18 patients had entirely recovered and 17 had experienced symptom improvement while all three patients without pretreatment deficits remained symptom-free (Table 2). In 13 patients, the symptoms remained unchanged, whereas one patient experienced a transient worsening before improvement. Only one patient reported a symptom worsening, consisting of a newly occurred pulsatile tinnitus during the first follow-up at 6 months.

3.3 Complications

After treatment delivery, only one acute complication occurred. One patient developed an edema around the tumor leading to mild to moderate pain irradiating to the ear, neck, and mandibula. The complication was treated with dexamethasone in an outpatient setting and did resolve shortly after (<72 hours). No radiation necrosis, seizures, acute bleedings, or other complications have been observed in the other 52 patients. Throughout follow-up, no radiation-induced malignancies occurred.

3.4 Quality of life

Before treatment delivery, 47 of 53 patients completed the SF12v2 questionnaire and answered all questions (return rate 88.6%). During first follow-up, which took place around 6 months after treatment (median: 6.1 months), 35 patients had filled out the questionnaire again (66.0% return rate).

Analysis of the data showed no significant decline in any of the eight Qol HC (Table 3; Figure 1). The category BP significantly improved compared with the baseline ($P = .04$), whereas MH showed a trend toward post-treatment improvement without reaching significance ($P = .08$). During the last patient follow-up, after a median of 38 months, 28 of 42 patients completed the SF12v2 as a total of 11 patients only had one follow-up.
| Authors/study | Year | Sample size (number of patients treated with robotic radiosurgery) | Median time of follow-up (months) | Median tumor size (cc) | Fractions (number) | Median dose (Gy) | Local control (%) | Quality of life results |
|--------------|------|---------------------------------------------------------------|----------------------------------|-----------------------|-------------------|----------------|------------------|----------------------|
| Lim et al\(^{24}\) | 2003 | 10 (4) GJTs | 26 | NR (mean diameter for 9 patients: 2.3 cc) | 1-3 | 18 | 100 | NR |
| Lim et al\(^{25}\) | 2004 | 13 with 16 GJTs (8 with 11 tumors) | Clinical: 41 Radiographic: 27 | NR (mean diameter: 3.0 cc) | 1-3 | 18.3 | 100 | NR |
| Lim et al\(^{26}\) | 2007 | 18 with 21 GJTs (13 with 16 tumors) | 35 | NR | 1-3 | 20 | 100 | NR |
| Tuniz et al\(^{27}\) | 2009 | 21 meningiomas, 9 schwannomas, 4 GJTs (34) | 31 | 19.3 | 2-5 | NR | 100 | No decline in all patients (no standardized measures reported) |
| Bianchi et al\(^{28}\) | 2009 | 9 (8) GJTs | NR (mean: 20) | 5.8 | 1-3 | 12.7 | 100 | NR |
| Lieberson et al\(^{17}\) | 2012 | 33 GJTs, 3 carotid body tumors, 3 glomus vagale tumors, 2 spinal parangliomas (30 with 35 tumors) | Clinical: 57.6 Radiographic: 46.8 | 4.6 | 1-5 | 20 | 100 (for 38 tumors) | NR |
| Golanov et al\(^{29}\) | 2012 | 34 (34) GJTs | NR (mean: 8) | NR (mean: 14.6) | 1-7 | NR (mean: 17) | 100 | NR |
| Hurmuz et al\(^{30}\) | 2013 | 14 (14) GJTs | 39 | 15.8 | 1-5 | 25 | 100 | NR |
| Chun et al\(^{31}\) | 2014 | 18 glomus jugulotympanicum, 12 GJTs, 1 carotid body tumor (31) | 24 | 8.2 | 5 | 25 | 100 | NR |
| Marchetti et al\(^{32}\) | 2017 | 20 patients with 17 jugulotympanic parangliomas, 4 carotid body parangliomas (21) | 35 (mean: 46) | 4 single-session PTV, 18.9 multisession PTV (mean for single-session: 4, mean for multisession 18.9) | 1-5 | 12 for single-session, 25 for multisession (mean for single-session: 12.2, mean for multisession 25.7) | 100 | NR |
visit (66.6% return rate). The results do not show any decrease in the measured QoL areas. All mean differences were at least zero or positive while no statistically significant improvement was identified. RP and VT showed trends toward improvement but failed to reach significance ($P = .06$ and $P = .08$). Values for PF and BP were normally distributed and analyzed with a paired two-tailed $t$ test. The remaining data were analyzed with Wilcoxon signed-rank tests.

### 3.5 Literature review

A total of 11 studies investigating RRS for GJTs or paragangliomas have been identified until February 1, 2019, the earliest study being published in 2003, the latest in 2017 (Table 4). Given the various studies from Stanford University, it was not possible to determine the exact number of cases treated. A total of approximately 148 GJTs or jugulotympanic paragangliomas have been treated with RRS with one or up to seven fractions. The LC for all tumors was 100% with median follow-up durations ranging from 24 to 57 months. The tumor size ranged from <1 to 69.2 cc. Only a few severe complications had been described and no standardized QoL results had been reported in any of the studies. Only 37 GJTs have been treated with single-session RRS. The published data does not allow for calculation of the median follow-up time, median dose, and average tumor size of this subgroup.

### 4 DISCUSSION

Herein, we report our long-term experience with RRS and its safety, efficacy as well as the impact on QoL of treated patients. To date, this study comprises the largest and most homogeneous series of patients treated with RRS and it is the first to provide standardized QoL measurements before and after treatment delivery. In agreement with previous RRS and radiosurgical studies, our LC rate was close to 100% (Table 4). We are the first to report a local recurrence of a tumor as other studies consistently reached LC rates of 100% with sometimes even longer median follow-up periods. Given the sparse data available, any prognostic factors are unclear so far. The recurrence after 5.9 years in one of our patients highlights the fact that GJTs can relapse even after a long follow-up, as discussed in various other studies. In addition, GJTs are usually slowly growing tumors with most of them having a tumor doubling time of more than 10 years and an average growth rate of less than 1 mm per year. Subsequently, long follow-up periods are

| Authors/study | Year | Sample size (number of patients treated with robotic radiosurgery) | Median time of follow-up (months) | Median tumor size (cc) | Fractions (number) | Median dose (Gy) | Local control (%) | Quality of life results |
|---------------|------|---------------------------------------------------------------|--------------------------------|----------------------|------------------|----------------|-----------------|-------------------------|
| Tosun et al.33 | 2017 | 12 with 3 GJTs, 5 carotid body tumors, 3 sympatetic paragangliomas, and 1 with bilateral neck paragangliomas (right neck; carotid body paraganglioma, left neck; GJT) (12) | 30 | 3.5 | 24 | 30 | 100 | No decline in QoL after treatment with significant improvement in BP |
| Current series | 2019 | 53 (53) GJTs | 38 | 4.3 | 1 | 16.5 | 98 | No decline in QoL after treatment with significant improvement in BP |

Abbreviations: cc, cubic centimeter; GJTs, glomus jugulare tumors; Gy, Gray; NR, not reported; PTV, planning target volume.
needed to detect relapses and to confirm the high LC rates initially reported in the current literature and herein.

Still, there are no consensus guidelines on how and when to treat GJTs. Some colleagues have argued that only fast-growing, large, catecholamine-secreting or symptomatic tumors should be treated.8,17,37

In young patients with hereditary tumors, chances of malignant GJTs are higher and, thus, should be treated in a timely manner as well.38,39 Lieberson and colleagues have proposed a treatment guideline including four primary options—surgery ± adjuvant radiation (conventional radiotherapy or radiosurgery), radiation alone or watchful waiting.17 Nevertheless, the decision making is not linked to the actual tumor size as the LC rates do not seem to be correlated with tumor size. This is also in agreement with the experience at our institution—larger tumors can be treated with good success. However, it is unclear to what extent fractionation plays a role in long-term tumor control as fractionated radiotherapy studies showed high tumor control rates as well.8,17 Based on our experience, RRS can be used in most of the cases and surgery may be reserved for patients with rapid neurological worsening and peripheral tumors. The primary use of RRS is still feasible regardless of the histological confirmation as the imaging findings and caused symptoms are usually sufficient to diagnose GJTs.40,41 For catecholamine-secreting tumors, it remains unclear which treatment is safe and most beneficial. We treated two hormone-secreting tumors, which caused syncope, tachycardia, and labile blood pressures. Despite short-term LC, cardiovascular symptoms remained unchanged and patients were lost to follow-up, emphasizing the need for interdisciplinary treatments including surgery. With regard to the proposed guidelines, more studies, ideally of prospective nature, are needed for verification.

In addition, future treatment guidelines should implement patient-centered outcomes including Qol analyses. Only sparse Qol data after radiotherapy and radiosurgery are available for paragangliomas and, more specifically, GJTs. It has been described that head and neck paragangliomas have a considerable impact on the Qol of affected patients.42,43 Galland-Girodet and colleagues reported that Qol significantly differs in a group of 30 head and neck paraganglioma patients according to the treatment modalities (surgery/embolization ± radiotherapy).44 Patients undergoing radiotherapy alone had better values for speech, hearing, trismus, and total score.44 Results were obtained retrospectively by mailing the EORTC-QLQ-C30 and EORTC-QLQ-H&N 35 questionnaire at least 12 months after treatment delivery.44 Recently, more data have been published by Patel and colleagues, investigating changes in Qol stratified by primary or secondary GK-based radiosurgery after a median of 97 months posttreatment delivery.45 Swallowing function was better in a group of 26 glomus jugulare patients undergoing primary radiosurgery. Overall and disease-specific measures did not significantly differ.45

To the best of our knowledge, we report the first standardized Qol data for GJT patients with pretreatment and follow-up comparisons using the SF12v2 questionnaire. Results show no decrease in any of the Qol concepts either during first or last follow-up with positive trends for RP, MH, and VT, whereas BP significantly improved in our series. These results confirm one of the essential features of RRS besides its high local tumor control, namely limiting negative impacts on the Qol from treatment delivery, especially in comparison with surgical treatment options.8,17 This is underlined by the observed symptom control and deficit improvements seen in two-third of our patients with pretreatment deficits. Various other studies using radiosurgery or radiotherapy reported similar experiences, with rates of stable or improved pre-treatment deficits ranging from 42% to 85%.17,21,32,46

## 4.1 Limitations

As inherent to retrospective clinical studies, reporting as well as selection biases cannot be ruled out.

In our case, we included every patient undergoing RRS since the availability of the technique at our institution in 2005. However, as the prevalence and incidence of GJTs is very low, we were only able to include 53 patients. Still, this is the most extensive series using RRS to date (Table 4) and one of the largest radiosurgical studies in the literature. This indicates the problem that even with our series, our patients might not be representative of the whole glomus jugulare population. Furthermore, our series include 33 primarily treated patients and histological confirmation of the tumor was not conducted.

Even though the radiological appearance including tumor location, contrast uptake, and clinical symptoms were characteristic for GJTs, we cannot completely exclude other possible diagnoses. Still, modern imaging techniques like CT, MRI, and angiography show high rates of sensitivity and specificity in the diagnosis of GJTs.40,41,47 In addition, our follow-up duration is still not long enough to reliably detect recurrences after 5 years or more. As previously described, relapses can occur even 40 years after treatment delivery.35 Finally, not all patients have fully completed the SF12v2 questionnaires before treatment and during follow-up. Hence, there could be selection and reporting biases in our Qol analyses.
5 | CONCLUSION

RRS is a safe, reliable, and efficient tool for the primary and secondary treatment of GJTs even for larger tumors. RRS achieves high rates of LC and leads to improved or stable pre-treatment deficits in most patients. This is also reflected by the Qol analysis showing no significant decrease in any of the Qol concepts during first or last follow-up with positive trends for RP, MH, and VT while BP significantly improved. RRS may be considered as a primary treatment option for most GJTs.

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