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Technical Notes & Surgical Techniques

Microsurgical removal of vestibular schwannomas with flexible hand-held 2µ-Thulium-fiber laser. Personal experience in 78 consecutive cases

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ABSTRACT

Aims: We performed a retrospective non-randomized study to analyze the results of microsurgery of vestibular schwannomas (VS) using 2µ-Thulium flexible hand-held laser fiber (Revolix jr®).

Methods: From September 2010 to November 2018, 180 patients suffering from VS have been operated on with microsurgical technique via retrosigmoid (RS) approach in our Department. From July 2012 to April 2018, tumor resection was performed in 78 cases with the assistance of 2µ-Thulium-fiber hand-held flexible laser. Facial nerve function was assessed with the House-Brackmann (HB) scale preoperatively, 1 week postoperatively, and 6-month after surgery.

Results: Overall time from incision to skin suture changed in relation to size of tumor (185–575 min) and was not affected by the use of laser. In 5 out of 78 cases preoperative facial nerve palsy HB2 and in one case HB4 (permanent) was observed. On considering 77 cases (excluding 1 permanent HB4) with a minimum 6-month follow-up, facial nerve preservation rate (HB1) was 92,2%. Hearing preservation rate (AAO-HNS A/B classes) was possible in 17 out of 30 cases (56,7%). Adopting a 0–3-scale, the mean surgeon satisfaction rate of usefulness of laser fiber was 2,75.

Conclusions: The use of 2µ-Thulium-fiber hand-held flexible laser in VS-microsurgery seems to be safe and to facilitate tumor resection, especially in "difficult" conditions (e.g., highly vascularized and hard tumors). In this retrospective trial, the good functional outcome following conventional microsurgery had not further improved, nor the surgical time reduced by laser. Focusing its use on "difficult" (large and vascularized) cases may lead to different results in future.

1. Introduction

The therapy of VS has changed during the years, from life-saving to preservation of function and quality of life. In particular, in the last two decades, the neurosurgical approach through retrosigmoid approach showed to be a safe and effective for surgery on VS of all sizes: intracanalicular without or with cerebellopontine angle extension, without and with contact and compression to brainstem [1,2]. Nowadays, preservation of facial nerve and hearing functions are the most relevant objectives in microsurgical treatment of these tumors, especially for VS with maximum diameter of 2 cm or less [3,4]. In complex tumors sometimes is difficult to respect these aims, e.g., in cases with 1. strong adherence of tumor to facial nerve, cochlear nerve, and brainstem; 2. hard consistence; or 3. high vascularization, with continuous bleeding during excision [4].

Lasers proved to be well-established instruments in different surgical fields for over 40 years [5–8]. Laser surgery in general showed various advantages, such as reduction of mechanical trauma and of intraoperative bleeding. A major advance in making lasers more useful in neurosurgical practice came with the introduction of continuous-wave lasers with flexible hand-held fiber [7]. This type of laser energy avoid the explosive effects of pulsed-wave lasers and allowed accurate cutting and vaporization by using focused beams, without the need to handle or retract the tissue [29]. In 2005, the development of flexible CO_2 laser fibers [6,7,9–12] transformed it in a hand-held tool. These new devices offer the possibility of guiding the laser beam by small and variable hand-held devices for direct microsurgical use [7,13–15].

Recently, 2µ-Thulium laser showed to be a promising device in the surgery of intracranial meningiomas [13], especially for debulking, shrinking, and coagulating the mass and its basal implant.

The laser vaporization and cutting of VS offers the possibility of removing large parts of the tumor without direct manipulations of the

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mass itself, reducing the mechanical trauma to the adherent seventh and eighth cranial nerves and to brainstem. In addition, laser proved to be more precise and less damaging the surrounding tissues than conventional bipolar cauterization [13,15,16].

First reports on brain tumors [5,7,13,14,16–21] and on VS operated on by middle fossa approach [22] and our own experience with 2μ-Thulium hand-held laser fiber in intracranial tumor surgery have been the rationale for applying this tool in "key hole" retrosigmoid removal of VS. Direct tumor laser ablation reduced mechanical manipulation of tumor itself, bipolar coagulation and ultrasonic aspiration, limited direct cutting with microscissors, with potentially better surgical results, especially in "complex" VS.

2. Materials and methods

2.1. Patients data

Seventy-eight consecutive patients with VS were considered. Inclusion criteria were: clinical and MRI diagnosis of VS and age of 18 years or older. Hearing preservation was attempted if functional hearing was AAO class A or B [23] in the affected side.

All patients were operated on by microsurgical technique combined with assistance of 2μ-Thulium flexible hand-held laser fiber (Revolix jr®), using the retrosigmoid (RS) approach, between July 2012 and September 2018. All cases with VS having maximum diameter 1 cm or less have been operated on without laser assistance. Demographic data were collected and the patients were asked about the symptoms of hearing loss, tinnitus, vertigo and other possible related neurological symptoms.

2.2. Determination of tumor size

Each patient received an MRI scan not exceeding 1 months before admission. Tumor was measured in three spatial dimensions (on axial and coronal MRI section planes) and tumor size was estimated considering its major diameter, including the part of tumor extending into the internal auditory canal.

2.3. Facial nerve function

Facial nerve function was assessed pre-operatively (clinically and with EMG), 1 week p.o. and 6 months p.o. using the House-Brackmann [24] (HB) classification (1: normal; 6: total paralysis).

2.4. Audiological data

In patients selected for hearing preservation (AAO class A or B) [23] audiological exams were performed pre-operatively as well as 1 week and 6 months p.o. by pure tone audiometry (PTA), auditory brainstem response (ABR), and monosyllabic speech audiograms.

2.5. Surgeon's evaluation of hand-held laser usefulness

The surgeon satisfaction rate of usefulness of hand-held flexible laser was evaluated adopting a 0–3-subjective-rating-scale (0 = not useful; 1 = moderately useful; 2 = useful; 3 = very useful).

3. Intra-operative procedures

3.1. Monitoring of facial and cochlear nerves

In all cases, facial nerve monitoring was used during all surgical procedure long (Nimbus i-Care 100®, IntraOperative Neurphysiological monitoring, Newmedic division of Hemodia, Labege, France), with electrodes inserted in orbicularis oris and orbicularis oculi muscles. The nerve stimulation was performed with monopolar (on the surface of tumor) or bipolar (close to the nerve) stimulator, starting from 2 mmAmp or more (on the capsule, for nerve course localization) to 0,3–0,05 mmAmp (directly on the nerve, for confirmation of its function).

As well as locating the course of the facial nerve, intraoperative monitoring of facial nerve helped in driving the use of laser fiber.

Each patients selected for hearing preservation received an ABR audiometry (Nicolet Viking III®, Viasys HealthCare, Madison USA/ Hochberg Germany) the day before surgery. In the last 12 cases we used ABR neuromonitoring evoked with CE-Chirp® stimuli (Interacoustics Eclipse EP15 ABR system) [25]. Among the 78 cases, there were 36 patients AAO class A or B, with reproducible responses that allowed a continuous intra-operative ABR-monitoring of the cochlear nerve.

3.2. Retrosigmoid approach

All operations were performed using the retrosigmoid (RS) approach. Continuous lumbar drain was placed in cases operated on for larger tumors (maximum diameter > 4 cm) and was left in place for 3–4 days, for facilitating cerebellar decompression during surgery and postoperative wound closure (draining around 10 cm^3/h).

Skin incision consists of a slightly curved 5–6 cm line behind the ear, about 1 cm posteriorly to the mastoid. Free pericranial flap is harvested for dural closure. The retrosigmoid-retromastoid lateral occipital bone is exposed including superior and inferior nuchal lines [4,15]. About 3 cm^2 craniotomy is performed in all cases, exposing sigmoid and transverse sinuses and the angle in between. The RS dura is opened in a semicircular shape, followed by lateral medullary cistern arachnoid opening for cerebellar detension by cerebrospinal fluid (CSF) aspiration. After cutting the dura covering the roof of internal auditory canal using the laser fiber, the opening of the canal is performer with a 4 mm extracoarse diamond burr or with Sonopet® Ultrasonic Aspirator (Stryker, Kalamazoo, MI) with dedicated bone tips. When adequate detension of cerebellar hemisphere is obtained, the tumor surface is exposed, with or without gentle retraction, and possible position of facial nerve searched with the use of stimulator.

According to the Fukushima's technique [4,15] a V-cut is usually performed on the dorsal surface of tumor with laser fiber and debulking of tumor obtained with microscissors, microcurettes, bipolar forceps, Sonopet® Ultrasonic Aspirator (usually VS with a maximum diameter higher than 2 cm) and hand-held Thulium laser for vaporizing and cutting. With standard microsurgical instruments (sharp dissectors, sickle knife, McElveen knife, straight and curved microscissors, ring and cup curettes) the tumor is separated from brainstem and cranial nerves during continuous facial and –in selected cases– cochlear nerve monitoring.

In cases with strong adhesion to brainstem and/or facial nerve, a millimetric fragment of tumor capsule is left.

Accurate haemostasis and tight dura closure using pericranial graft, haemostatics and sealants are performed and a fitted titanium net or the bone operculum is placed on the craniectomy with miniscrews.

3.3. Flexible 2μ-Thulium laser system

The capsule incision and tumor debulking has been performed with hand-held 2μ-Thulium flexible laser fiber (Revolix jr®, Lisa laser USA, Pleasanton, CA, USA). The range of power setting was 1–14 W. Standard 0,9% saline solution irrigation has been used for cooling the fiber (which is *not* hindered in its function by the presence of water). The fiber is used for cutting, vaporizing, and coagulating the capsule and the intracapsular mass, in combination with bipolar forceps, microscissors and Sonopet Ultrasound Aspirator. Following tumor debulking, the remaining tumor capsule is removed with standard microsurgical tools.

3.4. Determination of tumor removal and of procedure time

The amount of tumor removed has been assessed by surgeon's opinion and by postoperative contrast enhanced (c.e.) MRI performed within 1 week after surgery. The removal has been classified as total (100%), nearly-total (95–99%: millimetric residual frequently not detectable by MRI), subtotal (90–95%), and partial (< 90%).

Total operation time has been defined as the period lasting from skin incision until the end of skin suture.

3.5. Statistical analysis

Chi-square test was used to calculate differences in facial nerve and hearing preservation rates.

4. Results

4.1. Demographic and clinical data

Demographic, clinical, and MRI data were substantially irrelevant: 18 females and 20 males were included. Mean age was 50.7 years, and mean duration from first symptoms (hearing loss, tinnitus, vertigo, hemifacial numbness) until operation was 17.5 months; in 16 cases the tumor had one or more cysts inside. The mean maximum tumor size (including the extension into the internal auditory canal) was 2,73 cm. According to Samii's grading classification (34), the tumor belonged to grade II in 28 cases, grade III in 38, and in grade IV in 12; no patients in class I. In 12 patients (15,4%), preoperative clinical (6 cases) or electromyographic (6 cases) evidence of facial nerve impairment was observed (in one long lasting HB4). A serviceable preoperative hearing (AAO-HNS A and B classes) was present in 30 patients.

4.2. Tumor removal and operation time

Total tumor removal could be possible in 44 cases (Fig. 1). In accordance with patient's will, neither facial nor cochlear nerve (in cases of serviceable hearing) was sacrificed in order to obtain entire tumor resection. In relation to this consideration, a nearly-total or subtotal (90–99%) resection was performed in 22 cases (total + nearly total + subtotal in 66 cases: 84,6%).

In 12 cases a partial removal (< 90% of tumor) was only possible, because of tenacious adherences of the capsule of tumor to brainstem and to facial nerve; in all these cases, the tumor had a maximum diameter > 4 cm. The remnants were located into the conduct, or along the facial nerve course or adherent to brainstem.

Mean operation time (from incision to suture) changed in relation to size of tumor and ranged from 185 to 575 min: mean 325 min (SD 41.5).

Mortality and major permanent morbidity were zero. In 3 patients a transient abducens nerve (6th cranial nerve) palsy was observed, recovered within 6 month. One patient with large VS (3,5 cm maximum diameter) had swallowing disorders recovered completely within 3 months. In 5 cases a CSF leak from the surgical wound was observed and was resolved in all but two with continuous lumbar drain for 5–6 days; in 2 cases a surgical revision of the wound with dural repairment was necessary.

4.3. Facial nerve function

All patients were considered as HB1 pre-operatively, except 6 patients with HB2 to HB4 (long lasting) facial palsy; in other 6 cases, a preoperative subclinical involvement of facial nerve on electromyography was detected. The course of facial nerve was ventral-superior in 41,0%, ventral-inferior in 35,9% and ventral in 23,1% of cases.

At minimum 6-month postoperative follow-up, 71 of 78 patients had HB1 facial nerve function and 7 (9%) a dysfunction ranging from HB2 to HB4 (1 of them with definitive preoperative permanent deficit).

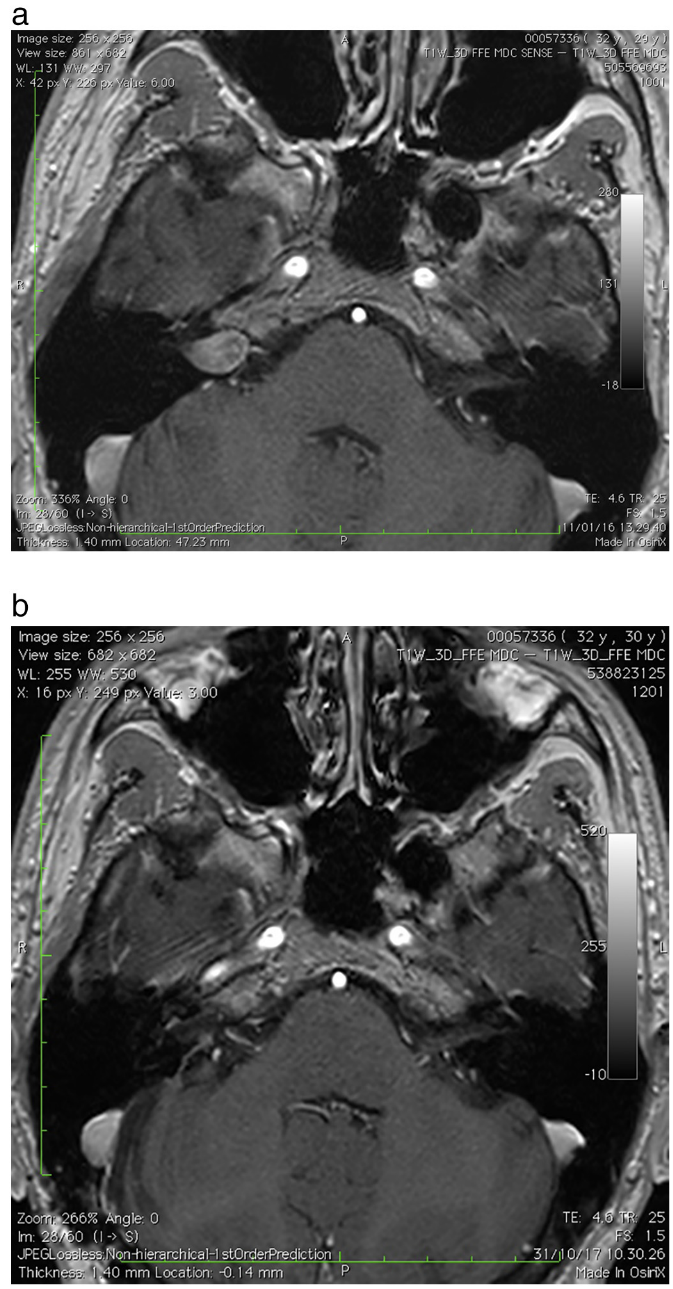

Fig. 1. a: Preoperative axial MRI showing a left intra- and extra-canalicular tumor with contrast enhancement.
b: Postoperative axial c.e MRI, at 3 years after surgery, confirming the total removal of VS.

In 31 cases the facial function was HB1 immediately after surgery; in these cases the mean maximum diameter of tumor was 2,2 (versus 3,4 cm of cases with transient facial deficit; $p < 0{,}03$).

Therefore, on considering 77 patients (1 excluded because of a preexisting long lasting HB4 facial deficit), the day after surgery a normal face was observed in 40,2% of patients and 6 months after operation HB1 facial nerve function was detected in 92.2%. When patients returned to normal face mobility, we never observed severe and permanent contractures.

4.4. Hearing results

Serviceable preoperative hearing (AAO-HNS A and B classes) was present in 30 patients. Among these, after operation 17 of them presented a hearing competence as before operation or slightly less valid (56,7%).

4.5. Surgeon's satisfaction rates

The mean surgeon satisfaction rate of usefulness of hand-held laser fiber was 2.75 ± 0,1 (ranging from 0 to 3).

In particular, the use of a hand-held flexible laser fiber appeared to be safe and easy to handle. It subjectively facilitated the tumor resection especially in "difficult" conditions (e.g., highly vascularized and hard tumors), avoiding traction and continuous suction, even if the good functional outcome following conventional microsurgery had not further improved, nor the surgical time reduced.

5. Discussion

The treatment of VS gradually changed over the years. Introduction of MRI into routine diagnostics of hearing disturbances showed increasing numbers of VS being detected at an early stage. It is still an open question if small tumors really need to be treated or not (wait-and-see); anyway, irreversible hearing loss has to be expected in > 50% of patients in the course of their life [26–33].

According to the clinical experience and to the literature, the most common options are: surgical excision, radiosurgery (gamma-knife and Cyber-knife) [34,35], and "wait and scan" with serial clinical and MRI controls. In accordance with outstanding experienced neurosurgeons [3,4,15,36], we recommend microsurgery as first treatment of VS, suggesting radiosurgery in patients with growing recurrent tumors not suitable for re-surgery because of compromised general conditions. In patients with small VS (under 2 cm of maximum diameter) with hearing loss, wait and control the possible growth of tumor with serial MRI seems to be the most reasonable option, especially in patients older than 65 years. In cases with large tumors or with small tumors with a serviceable hearing we usually prefer the surgical option.

Life-threatening complications related to surgical treatment of VS are rare and preservation of functions is the goal [3,4,36]. Anyway, patients with larger tumors compressing and displacing brainstem are more challenging and other possible postoperative side effects have to be considered, such as trigeminal, abducens, and lower cranial nerves deficits. In our series no major complications nor permanent deficits have been observed; in 8 patients minor transient complications were related to CSF circulation (wound fistulas and CSF leak), in all but one cases resolved conservatively.

The intra-operative cochlear and facial nerve monitoring has improved the preservation rates of facial and cochlear nerve functions, if patients had a serviceable preoperative hearing (AAO-HNS A and B classes). In our series, we obtained quite good results both for facial nerve outcome and hearing preservation in both groups.

Laser assisted VS surgery has been described in several studies, mostly using a retrosigmoid and/or translabyrinthine approach [12,37,38] and in the literature there is no completely uniform opinion on an additional advantage of this special non-contact tool. Discussion of the value of hand-held laser assistance in VS surgery for facial nerve outcome has been heterogeneous to date: Cerullo et al. [12] and Eiras et al. [37] demonstrated some advantage with its use in patients with larger tumors. Nissen et al. [39] reported a normal facial function in 90% in tumors smaller than 1.5 cm. On the other hand, Zaouche et al. [38] described a slightly worse outcome in VS of operations performed with a laser fiber.

In our series, at minimum 6-month follow up, HB1 facial nerve function was observed in 92,2% of cases. As regarding hearing function, it was preserved in 56,7% of patients with serviceable preoperative hearing (AAO-HNS A and B classes).

The temporary facial palsy is usually related to necessary microsurgical dissection during separation of tumor from the nerve. The intensity of mechanical manipulations depends on the conditions of facial nerve and on the adherence of the tumor shell to the nerve itself and, consequently, on tumor dimensions. Our long-term rate facial results are comparable to other reports [1,4,28,36,38,40–42]. Therefore, the use of the 2μ-Thulium-laser in proximity of the nerve seems to be safe enough in the RS approach, especially if surgeon always has a direct view of the facial nerve.

The same findings apply for the necessary manipulations of the cochlear nerve. Results of hearing preservation in VS-surgery have also improved over the past decades, especially in treatment of smaller tumors. In our series, the recent use of intraoperative ABRs with CE-Chirp stimulus [25] improved the intraoperative monitoring of hearing, with quick brainstem evoked responses after the stimulus. For attempting hearing preservation we selected patients belonging to classes A and B of the AAO-HNS classification [3,4,23,33,43–48].

Eiras et al. [37] compared resection time with or without laser fiber in giant VS operated by RS approach and reported that laser resection takes longer as well. On the other hand, in our series the operation time (185 to 575 min: mean 325 min) was not influenced by hand-held laser assistance and was in relation to tumor size. Moreover, vascularization of the tumor as well as its adherence to brainstem and to facial and cochlear nerves may lead to prolonged resection time, either by haemostatic procedures. One of the most important factors seem to be the repeated interruptions during tumor removal due to worsening of intraoperative facial and ABR responses, which necessitate recovery periods for the nerves without any further microsurgical manipulations.

As reported previously [49,50] on a limited cohort of patients, in the present series the use of a hand-held flexible laser fiber seemed to be safe. The rate of usefulness evaluated by the mean surgeon satisfaction rate was 2.75 (according to a scale ranging from 0 to 3). In some cases the use of the 2μ-Thulium laser fiber was considered very helpful and, subjectively, facilitated the tumor excision especially in "difficult" conditions (e.g., highly vascularized and hard tumors), avoiding tractions and continuous suction with ultrasonic aspirator. Anyway, on the basis of our retrospective analysis, the good functional outcome following conventional microsurgery showed to be not further improved nor the surgical time reduced by the laser fiber. On the basis of our preliminary experience, it seems to be that focusing the use of 2μ-Thulium hand-held flexible laser fiber on large and vascularized VS may lead to better results in future.

6. Conclusion

In our retrospective series on 78 consecutive cases, the use of 2μ-Thulium flexible hand-held laser fiber in VS surgery by "key-hole" RS approach proved to be safe, but did not have significant influence on postoperative facial nerve function, hearing preservation rate nor surgical time. On the other hand, according to surgeon impression, in highly vascularized tumors the necessary reduction of tumor volume before microsurgical dissection of facial and cochlear nerve appears to be easier with 2μ-Thulium flexible hand-held laser fiber in association with ultrasonic aspirator and microsurgical dedicated instruments.

Conflict of interest

All authors certify that they have NO affiliations with or involvement in any organization or entity with any financial interest (such as honoraria; educational grants; participation in speakers' bureaus; membership, employment, consultancies, stock ownership, or other equity interest; and expert testimony or patent-licensing arrangements), or non-financial interest (such as personal or professional relationships, affiliations, knowledge or beliefs) in the subject matter or materials discussed in this manuscript.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.inat.2019.01.008.

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