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Treatment of redo-microvascular decompression or internal neurolysis plus microvascular decompression for recurrent trigeminal neuralgia: a review of long-term effectiveness and safety

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Abstract

Objective: We examined the clinical characteristics and outcomes of patients with recurrent trigeminal neuralgia (TN) and assessed the long-term efficacy and safety of microvascular decompression (MVD) to treat typical recurrent TN.

Methods: We identified 3024 patients who underwent MVD for treatment of TN at the China-Japan Friendship Hospital from March 2009 to December 2020. We retrospectively analyzed the data and outcomes of 137 patients who underwent redo-MVD and 74 patients who did not undergo redo-MVD as the control group. These outcomes were evaluated using the Barrow Neurological Institute scoring system.

Results: Recurrence in 68 of the 137 patients was due to incomplete or absent decompression or new responsible vessels. To ensure thorough pain relief, redo-MVD should include decompression of both the trigeminal root entry zone and the peripheral nerve segments, where blood vessels can cause symptoms. Factors associated with reduced effectiveness of redo-MVD were no period of initial pain relief after the first MVD and a longer duration of symptoms before the first MVD.

Conclusions: Redo-MVD should not be excluded as a treatment option for patients with refractory TN who develop recurrent pain after a first MVD procedure.

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Introduction

Trigeminal neuralgia (TN) is a chronic pain condition that causes abrupt, searing facial pain.[1] It occurs in 4 to 27 of 100,000 people annually and has been called the "suicide disease" because of the severity of pain, which results in poor quality of life.[2] There are two types of TN: typical, marked by sharp pain from specific triggers, and atypical, characterized by a persistent dull ache. The primary cause of typical TN is an impingement on the trigeminal nerve by a neighboring blood vessel, known as neurovascular compression (NVC). The surgical treatment for this condition is microvascular decompression (MVD), which relieves pressure on the trigeminal nerve.[3] MVD brings maximum benefit for most patients with typical TN for whom medication has proven insufficient.[4] In comparison with ablative treatments, such as percutaneous balloon compression, radiofrequency thermocoagulation, or stereotactic radiosurgery, all of which damage the nerve to limit its ability to transmit pain signals, MVD is a more reliable treatment because of its long-term success in preventing pain and its low risk of complications.[5] Despite this success, however, MVD commonly recurs, with 10% to 30% of patients experiencing a return of symptoms.[6,7] Few studies have examined the role and efficacy of MVD in the treatment of recurrent TN. In this study, we examined the clinical characteristics and outcomes of patients with recurrent TN and assessed the long-term efficacy and safety of MVD for treatment of typical recurrent TN. Our overall goal was to optimize the treatment procedures for patients with TN.

Patients and methods

Patient sample and study design

To examine the efficacy and safety of MVD in the treatment of typical TN, we identified 3024 patients with TN who underwent MVD at the Department of Neurosurgery, China-Japan Friendship Hospital from March 2009 to December 2020. Patients were excluded from the study if they exhibited atypical TN or had incomplete clinical data. After treatment with MVD and pain amelioration, 247 patients experienced recurrence of symptoms. Of these, 137 patients with recurrent symptoms after the first MVD elected to undergo a redo-MVD treatment. We selected 74 patients who did not undergo repeat MVD as the control group (Figure 1).

Recurrent TN was defined as the recurrence of TN pain on the same side for at least 6 months after a previously successful MVD procedure with complete pain relief. The primary inclusion criteria in this study were based on the International Classification of Headache Disorders, 3rd edition: typical drug-resistant TN or drug-responsive TN but with severe drug-related adverse effects, and no absolute contraindications to general anesthesia.[7] The exclusion criteria were contraindications to

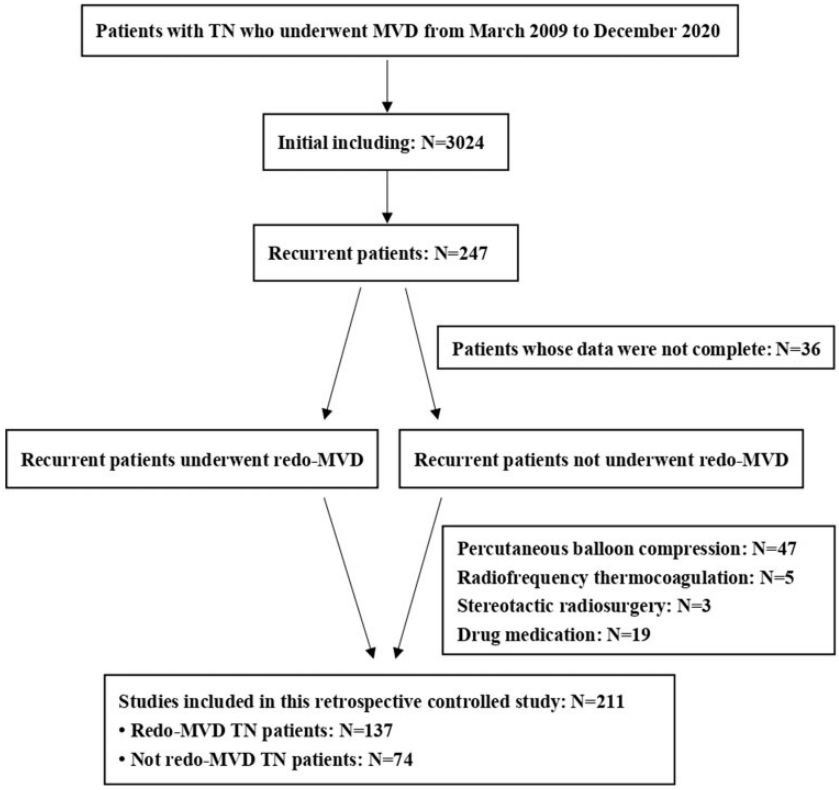

Figure 1. Flow chart of patient selection.
TN, trigeminal neuralgia; MVD, microvascular decompression.

general anesthesia, patient refusal to undergo redo-MVD, and incomplete data. Magnetic resonance imaging (MRI) was performed on all patients to assess the trigeminal nerve roots and adjacent anatomical structures before the operation. Based on previous studies, we divided the MRI findings of NVC into three categories: no vascular compression, only contact (the vessel touches the nerve without visible alteration of the nerve, and cerebrospinal fluid cannot be seen between the nerve and the vessel), and obvious compression (the nerve root exhibits displacement, distortion, or indentation). We also judged the type of offending vessel on MRI. Moreover, we assessed the size of the posterior fossa volume based on previously reported MRI assessment methods or intraoperative conditions, which were evaluated as previously described.[8] All treatments were carried out by the corresponding author (Y.Y.). All participating patients provided written informed consent, and the Ethics Committee of the China-Japan Friendship Hospital approved this study.

Surgical technique

After induction of general anesthesia, the patients were placed in the lateral decubitus position with the affected side facing upward. As in the initial surgery, redo-MVD was performed via a standard suboccipital retromastoid craniotomy. The primary goal of the repeat MVD treatment was to alleviate recurrent pressure on the

trigeminal nerve induced by either a blood vessel or a granuloma that had formed secondary to the Teflon felt inserted during the first operation. In the case of arterial loop compression, additional Teflon felt was inserted between the trigeminal nerve and blood vessel. If a Teflon granuloma was observed, the fibrotic adhesion was completely excised through sharp microsurgical dissection, and no additional Teflon was added to avoid additional fibrotic adhesion. Following these procedures, the stitched sling retraction technique was performed, which slings the offending artery in an appropriate direction to limit impingement on the trigeminal nerve. Finally, if the exploration proved negative, we performed dissection and lysis of the adjacent arachnoid followed by an internal neurolysis or nerve combing procedure on the trigeminal root.

Data collection

The patients' medical records provided information about their medical history and baseline health data, including sex, age, type of TN (typical or atypical), sidedness and duration of pain symptoms, affected division of the trigeminal nerve, type of blood vessel involved, degree of decompression, volume of the posterior fossa, presence/absence of thickening of the arachnoid, and outcomes of the first and second surgical procedures, where applicable. These outcomes were evaluated using the Barrow Neurological Institute (BNI) scoring system[9] (Table 1). Patients with complete pain relief were assigned a BNI score of I, those with partial pain relief were assigned scores of II to III, and those with no improvement or recurrence of symptoms were assigned scores of IV to V.[10] The surgical results were assessed through outpatient services and telephone interviews yearly for at least 1 year postoperatively to document any complications and recurrence.

Table 1. Barrow Neurological Institute pain intensity scores.

Score	Description
I	No pain, no medication required
II	Occasional pain, no medication required
III	Some pain, adequately controlled with medications
IV	Some pain, not adequately controlled with medications
V	Severe pain or no pain relief

Statistical analysis

IBM SPSS Statistics for Windows, Version 24.0 (IBM Corp., Armonk, NY, USA) was used for all statistical tests, with a p value of <0.05 considered statistically significant. Clinical features and patient characteristics are summarized by descriptive statistics. Categorical variables are expressed as numbers and percentages, and quantitative data are presented as mean $\pm$ standard deviation. Student's *t*-test was used for comparisons between two sets of data. Fisher's exact test or a nondirectional chi-square test was used for comparisons of proportions between groups of patients. Spearman's ρ was used to conduct a univariate analysis of prognostic factors. Outcomes between the two groups (redo-MVD and no redo-MVD) were assessed using a Kaplan–Meier survival analysis, including the time interval. A log-rank test was further used to compare the long-term results between the two surgical groups.

Results

Patients' characteristics

Clinical and demographic information of the patients in the redo-MVD and no redo-MVD groups was collected and summarized. Thirteen patients in the redo-MVD group and eight patients in the no

redo-MVD group had undergone previous treatments, including percutaneous balloon compression, stereotactic radiosurgery, and radiofrequency thermocoagulation (Table 2). The no redo-MVD group experienced a significantly longer duration of symptoms before surgery than did the redo-MVD group ($p = 0.002$). The prevalence of arachnoid thickening adhesion was significantly higher in the redo-MVD group than in the no redo-MVD group ($p < 0.037$). There were no detectable differences in sex, sidedness of pain, affected division of the trigeminal nerve, or volume of the posterior fossa between the two groups.

Operative findings of redo-MVD

All 137 patients in the redo-MVD group showed moderate to severe adhesions. Trigeminal nerve compression was caused by Teflon compression or adhesion in 37 (27.1%) patients, superior cerebellar artery compression in 28 (20.4%), super petrosal vein compression in 18 (13.1%), anterior inferior cerebellar artery compression in 9 (6.6%), basilar artery compression in 5 (3.6%), and posterior inferior cerebellar artery compression in 4 (2.9%). In the remaining 36 (26.3%) patients, no obvious compression was observed. Treatment in the redo-MVP group was performed in accordance with these findings. For the 37 patients with Teflon compression or adhesion, complete excision of the Teflon felt was performed. For the 64 patients with vascular compression, decompression was achieved by placing Teflon felt between the affected region of the trigeminal nerve and the impinging blood vessel. For the 36 patients with no observed compression,

Table 2. Clinical characteristics of the redo-MVD and no redo-MVD groups.

Patient characteristics	Redo-MVD	No redo-MVD	p
Age, years	62.48 ± 9.35	64.13 ± 13.29	0.057
Sex, male/female	40/97	27/47	0.618
Side of pain, right/left	81/56	39/35	0.175
Duration of symptoms, years	7.57 ± 3.19	9.23 ± 4.35	0.002
Division affected			0.593
V1	5 (3.6)	4 (5.4)	
V2	38 (27.7)	28 (37.8)	
V3	24 (17.5)	7 (9.4)	
V1 + V2	12 (8.8)	21 (28.4)	
V2 + V3	47 (34.3)	11 (14.9)	
V1 + V2 + V3	11 (8.1)	3 (4.1)	
Previous treatments			
Percutaneous balloon compression	10	2	
Stereotactic radiosurgery	2	2	
Radiofrequency thermocoagulation	1	4	
Posterior fossa volume			0.749
Normal	59 (43.1)	33 (44.6)	
Small	78 (56.9)	41 (55.4)	
Presence of arachnoid thickening adhesion			0.037
Yes	112 (81.8)	57 (77.1)	
No	25 (18.2)	17 (22.9)	

Data are presented as mean ± standard deviation, n, or n (%).
MVD, microvascular decompression.

trigeminal root decompression was performed.

Postoperative outcomes and complications

In the no redo-MVD group, treatment was effective in 41 (55.4%) patients with postoperative BNI scores indicating immediate and complete pain relief. Twenty-five (33.8%) patients reported partial pain relief, and eight (10.8%) patients reported no pain relief. In the redo-MVD group, 109 (79.6%) patients had BNI scores indicating immediate and complete pain relief. Twenty-two (16.1%) patients reported some degree of partial pain relief, and only six (4.3%) patients reported no pain relief (Table 3).

At the last follow-up, the long-term pain relief outcomes showed that 38 (51.3%) patients in the no redo-MVD group were completely pain-free, 23 (31.1%) patients experienced differing degrees of partial pain relief, and 13 (17.6%) patients reported no pain relief. In the redo-MVD group, 89 (65.0%) patients were completely pain-free at the last follow-up, 36 (26.3%) patients reported differing degrees of partial pain relief, and 12 (8.7%) patients reported no pain relief (Table 3).

Complications

Complications or side effects were rare in both the redo-MVD and no redo-MVD groups. After the procedures, no severe complications such as paralysis, stroke, or death were observed.

In the redo-MVD group, 25 (18.2%) patients reported postoperative abnormal facial sensation, though only 12 (8.7%) patients reported this as bothersome at the last follow-up. Other postoperative complications included intracranial infection in 13 (9.5%) patients, wound infection in 10 (7.3%), hearing loss in 8 (5.8%), intracranial bleeding in 2 (1.5%), and continuous pain in only 1 (0.7%) (Table 4).

In the no redo-MVD group, 22 (29.7%) patients reported postoperative abnormal facial sensation, with 17 (23.0%) reporting issues at the last follow-up. Other postoperative complications included intracranial infection in three (4.1%) patients, wound infection in one (1.3%), hearing loss in three (4.1%), and continuous pain in five (6.7%) (Table 4).

Predictive factors of postoperative outcomes

Univariate analysis indicated that long-term failure of redo-MVD was predicted by a longer duration of symptoms at the

Table 3. Comparison of surgical outcomes for patients with TN between the redo-MVD and no redo-MVD groups.

Variable	Redo-MVD	No redo-MVD	p
Immediate outcome			
Complete pain relief	109 (79.6)	41 (55.4)	0.001
Partial pain relief	22 (16.1)	25 (33.8)	<0.001
Failure	6 (4.3)	8 (10.8)	0.002
Long-term outcome			
Complete pain relief	89 (65.0)	38 (51.3)	0.001
Partial pain relief	36 (26.3)	23 (31.1)	0.012
Failure	12 (8.7)	13 (17.6)	<0.001

Data are presented as n (%).

TN, trigeminal neuralgia; MVD, microvascular decompression.

Table 4. Comparison of postoperative complications experienced by patients with TN between the redo-MVD and no redo-MVD groups.

Complication	Redo-MVD	No redo-MVD	p
None	78 (57.0)	40 (54.1)	0.011
Abnormal facial sensation	25 (18.2)	22 (29.7)	<0.001
Intracranial infection	13 (9.5)	3 (4.1)	0.009
Wound infection	10 (7.3)	1 (1.3)	<0.001
Hearing loss	8 (5.8)	3 (4.1)	0.014
Intracranial bleeding	2 (1.5)	0 (0.0)	0.098
Continuous facial pain	1 (0.7)	5 (6.7)	<0.001

Data are presented as n (%).
TN, trigeminal neuralgia; MVD, microvascular decompression.

time of the first MVD ($p < 0.05$). Long-term failure of redo-MVD was also likely when patients experienced no pain relief after the first MVD ($p < 0.05$). Other variables, such as age, sex, sidedness of pain, distribution of pain, posterior fossa volume, or arachnoid thickening adhesion, were not predictive of surgical success rates.

Discussion

MVD was first proposed in the 1960s by Jannetta[11] as a treatment of TN caused by vascular compression of the trigeminal nerve. After many years of development, MVD is now the most common surgical approach and the only treatment that cures the underlying problem of vascular compression.[12] MVD is largely successful, with long-term relief reported in 70% to 80% of patients 5 to 10 years after surgery.[13,14] However, 10% to 30% of patients report incomplete or no pain relief.[6] Although MVD can be performed more than once in the same patient, little is known about the efficacy, safety, and long-term outcomes of a second procedure.

In this study, we identified 3024 patients who underwent MVD for treatment of TN at the China-Japan Friendship Hospital from March 2009 to December 2020. Recurrence after initial pain improvement occurred in only 247 (8.2%) of these patients, which is a lower rate than in other studies.[15,16] We retrospectively analyzed the data and outcomes for 137 patients who elected to undergo redo-MVD and 74 patients who did not undergo redo-MVD as the control group, including 47 patients who had previously undergone percutaneous balloon compression, 5 who had undergone radiofrequency thermocoagulation, 3 who had undergone stereotactic radiosurgery, and 19 who had undergone drug therapy. We compared the long-term outcomes between the redo-MVD group and no redo-MVD group to determine the effectiveness and safety of the procedure.

Our findings indicate that redo-MVD is an effective and safe treatment for patients with incomplete pain relief after an initial MVD procedure. However, pain relief after a redo-MVD procedure is not entirely consistent and is dependent on the medical history, surgical approach, and, most importantly, the effectiveness of decompression of the offending blood vessels. If patients with recurrent TN are able to withdraw from drug therapy after the initial MVD, they will be more aware of the effects of the drug on their mood and cognitive function. When TN returns, the patient may opt for no medical management based on this subtle but significant effect.[17] Compared with percutaneous balloon compression, stereotactic radiosurgery, and

radiofrequency thermocoagulation, all of which are associated with a high likelihood of recurrence and sensory deficits, redo-MVD reportedly has good outcomes in the management of recurrent TN.[18–20]

Recurrence in 64 of 137 patients in this study was due to incomplete or absent decompression or new responsible vessels. To ensure thorough pain relief, redo-MVD should include decompression of both the trigeminal root entry zone and the peripheral nerve segments, where blood vessels can cause symptoms. This problem underscores the advantage of using MRI to identify morphologic changes in the trigeminal root. Another common reason for pain recurrence is the development of a Teflon granuloma at the placement site. In this study, 37 (27.1%) patients who underwent redo-MVD had developed a Teflon granuloma. This rate is lower than those reported in previous studies and may have been affected by the surgical methods.[7] In patients who underwent redo-MVD for treatment of recurrence due to a Teflon granuloma, we excised the Teflon felt from the affected site. A granuloma can be diagnosed with MRI, where it appears as a lesion with low to intermediate signal intensity on T1/T2 sequences. The application of standardized MRI criteria for identifying NVC may aid in selecting patients with recurrence for redo-MVD. For these patients, the best approach is redo-MVD together with removal of the Teflon granuloma. Importantly, among the patients who underwent a failed MVD procedure, 36 (26.3%) showed no obvious NVC. Trigeminal root compression was performed in these patients. We added internal neurolysis or nerve combing during the redo-MVD procedure, which can limit the trauma to the nerve after careful dissection and lysis of the surrounding arachnoid and has been shown to be an effective intervention for TN in the absence of NVC.[21] Notably, Ko et al.[22] found that internal neurolysis is a safe and effective alternative operation for TN without NVC, reporting that 85% of patients were pain-free and 96% experienced pain relief, with 1- and 5-year pain-free survival rates of 58% and 47%, respectively.

Additionally, Zhang et al.[23] reported that nerve combing plus MVD is a better choice for patients with a poor response to initial MVD and that this technique significantly improved the success rate of the operation and achieved good long-term surgical outcomes.

Our findings regarding both early and longer-term pain relief after redo-MVD or internal neurolysis plus MVD are similar to previously published estimates.[24–26] In our study, initial pain relief was reported by 95.7% of patients in the redo-MVD group, which is comparable with 89.2% in the control no redo-MVD group and with other studies that showed initial pain relief rates of 80% to 96%.[7] We followed up our patients for 1 to 12 years, with at least 30% of patients followed up for $\geq$5 years. This long-term monitoring showed that 91.3% of patients who underwent redo-MVD continued to have significant pain relief (BNI scores of I–III) and that 65% of these patients were completely pain-free (BNI score of I). Previous studies similarly showed that 54% to 84% of patients were completely pain-free at their most recent visit, with an average duration of 2 to 8 years.[12,27–30]

During surgery, surgeons should avoid disturbance or stretching of the trigeminal nerve to the maximum extent possible and should also avoid the occurrence of postoperative paroxysmal facial numbness caused by electrocoagulation. We found that the incidence of postoperative wound infection was higher in the redo-MVD group than in the control no redo-MVD group, which may have been related to the prolonged operative time due to increased postoperative adhesion during reoperation.

Postoperative adhesion caused by the primary surgery may also increase the risk of postoperative facial numbness during the second surgery. However, there was a lower incidence of postoperative abnormal facial sensation in the redo-MVD group. In the no redo-MVD group, the increased rate of postoperative facial numbness might have been related to excessive trigeminal nerve interference during percutaneous balloon compression, stereotactic radiosurgery, or radiofrequency thermocoagulation. Other studies have revealed similar findings: one study showed that 52% of patients experienced facial numbness after repeat posterior fossa exploration,[30] and another showed that 27% of patients experienced facial numbness after redo-MVD.[29] However, a meta-analysis demonstrated no difference in the rate of postoperative facial numbness or retreatment in a comparison of repeat MVD versus stereotactic radiosurgery for recurrent TN after failure of primary stereotactic radiosurgery.[31]

The previous school of thought was that less invasive surgeries should be the first option for patients who have undergone a failed first MVD because of the potential risks and complications thought to be associated with repeat MVD. However, our results showed that redo-MVD can still yield good results in patients continuing to experience pain after a first MVD, particularly if other treatments or approaches have proved ineffective.

Patients and their doctors considering a repeat MVD should be aware of factors that might limit the success of the procedure. In our study, the univariate analysis showed that patients for whom the initial surgery was entirely ineffective in providing pain relief and patients with a longer duration of symptoms before the first MVD received less benefit from redo-MVD. A previous study also showed that two prognostic factors for a failed redo-MVD included an initial surgery that was ineffective at providing pain relief, including no pain relief after the initial surgery, and negative findings during the reoperation.[24] Other studies have suggested that the type of NVC may affect the success of MVD, with arterial compression being more easily resolved.[8,32] Preoperative imaging with high-resolution MRI is recommended for confirmation of NVC.[33] The best candidates for redo-MVD are patients who experience an initial period of pain relief after the first MVD or in whom imaging demonstrates vascular compression.

This study had two main limitations. First, the small sample size was small because of the limited number of patients with recurrent TN who opted for an alternative therapeutic intervention suitable for comparison with redo-MVD. Given the importance of selecting the correct group for comparison, our control group comprised 74 patients who did not undergo redo-MVD and instead opted for continued medical management or other surgical treatments as a therapeutic intervention. We cannot rule out the possibility that the differences in the observed outcomes in this study were due to differences in the baseline characteristics between the two groups. Thus, further studies that can expand the comparison group of patients with recurrent TN with comparable interventions are required for validation of the efficacy of redo-MVD. Second, the follow-up duration was limited to at least 1 year, and 36 patients were lost during the follow-up process. As a result, the long-term efficacy data are incomplete.

Conclusions

Our study demonstrated that redo-MVD should not be excluded as a treatment option in the management of patients with refractory TN who develop recurrent pain after a first MVD procedure. Redo-MVD can provide pain relief for patients with

recurrent TN. The procedure is largely safe and effective, although it is not entirely without risk. Some factors are associated with reduced effectiveness of redo-MVD, including no period of initial pain relief after the first MVD and a longer duration of symptoms before the first surgery. Thus, not all patients are suitable for redo-MVD. Our data can be used by surgeons to guide decision-making for each individual case as well as give informed counsel to patients regarding treatment after failed MVD.

Author contributions

Baisheng Wang performed the literature search, analyzed the data, and wrote the manuscript. Baisheng Wang and Li Zhang performed the literature search and analyzed the data. Yanbing Yu designed the study, analyzed the data, and critically reviewed the manuscript.

Declaration of conflicting interest

The authors declare that there is no conflict of interest.

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References

1. Cruccu G, Di Stefano G and Truini A. Trigeminal neuralgia. *N Engl J Med* 2020; 383: 754–762. DOI: 10.1056/NEJMra1914484.
2. Araya EI, Claudino RF, Piovesan EJ, et al. Trigeminal neuralgia: basic and clinical aspects. *Curr Neuropharmacol* 2020; 18: 109–119. DOI: 10.2174/1570159X17666191010094350.
3. Di Stefano G, Truini A and Cruccu G. Current and innovative pharmacological options to treat typical and atypical trigeminal neuralgia. *Drugs* 2018; 78: 1433–1442. DOI: 10.1007/s40265-018-0964-9.
4. Singh D, Dutta G, Jagetia A, et al. Microvascular decompression for trigeminal neuralgia: experience of a tertiary care center in India and a brief review of literature. *Neurol India* 2021; 69: S206–S212. DOI: 10.4103/0028-3886.315975.
5. Amaya Pascasio L, De La Casa-Fages B, Esteban de Antonio E, et al. Microvascular decompression for trigeminal neuralgia: a retrospective analysis of long-term outcomes and prognostic factors. *Neurologia (Engl Ed)* S0213-4853(21)00071-2. 2021/05/30 (online ahead of print). DOI: 10.1016/j.nrl.2021.03.009.
6. Sanchez-Mejia RO, Limbo M, Cheng JS, et al. Recurrent or refractory trigeminal neuralgia after microvascular decompression, radiofrequency ablation, or radiosurgery. *Neurosurg Focus* 2005; 18: e12.
7. Liu J, Wu G, Xiang H, et al. Long-term retrospective analysis of microvascular decompression in patients with recurrent trigeminal neuralgia. *Front Neurol* 2020; 11: 584224. 2021/01/08. DOI: 10.3389/fneur.2020.584224.
8. Liu R, Deng Z, Zhang L, et al. The long-term outcomes and predictors of microvascular decompression with or without partial sensory rhizotomy for trigeminal neuralgia. *J Pain Res* 2020; 13: 301–312. DOI: 10.2147/JPR.S225188.
9. Rogers CL, Shetter AG, Fiedler JA, et al. Gamma knife radiosurgery for trigeminal neuralgia: the initial experience of The Barrow Neurological Institute. *Int J Radiat Oncol Biol Phys* 2000; 47: 1013–1019.
10. Gao J, Fu Y, Guo SK, et al. Efficacy and prognostic value of partial sensory rhizotomy and microvascular decompression for primary trigeminal neuralgia: a comparative study. *Med Sci Monit* 2017; 23: 2284–2291. 2017/05/16. DOI: 10.12659/msm.901510.
11. Jannetta PJ. Arterial compression of the trigeminal nerve at the pons in patients with trigeminal neuralgia. 1967. *J Neurosurg* 2007; 107: 216–219.
12. Sarsam Z, Garcia-Fiñana M, Nurmikko TJ, et al. The long-term outcome of microvascular decompression for trigeminal neuralgia. *Br J Neurosurg* 2010; 24: 18–25. DOI: 10.3109/02688690903370289.

13. Wang DD, Raygor KP, Cage TA, et al. Prospective comparison of long-term pain relief rates after first-time microvascular decompression and stereotactic radiosurgery for trigeminal neuralgia. *J Neurosurg* 2018; 128: 68–77. DOI: 10.3171/2016.9.JNS16149.
14. Barker FG, Jannetta PJ, Bissonette DJ, et al. The long-term outcome of microvascular decompression for trigeminal neuralgia. *N Engl J Med* 1996; 334: 1077–1083.
15. Jafree DJ, Williams AC and Zakrzewska JM. Impact of pain and postoperative complications on patient-reported outcome measures 5 years after microvascular decompression or partial sensory rhizotomy for trigeminal neuralgia. *Acta Neurochir (Wien)* 2018; 160: 125–134. 2017/10/31. DOI: 10.1007/s00701-017-3350-6.
16. Akkaya E, Gokcil Z, Erbas C, et al. A clinical analysis of microvascular decompression surgery with sacrification of the superior petrosal venous complex for trigeminal neuralgia: a single-surgeon experience. *Turk Neurosurg* 2020; 30: 83–88. 2019/10/15. DOI: 10.5137/1019-5149.Jtn.26555-19.3.
17. Eddy CM, Rickards HE and Cavanna AE. The cognitive impact of antiepileptic drugs. *Ther Adv Neurol Disord* 2011; 4: 385–407. DOI: 10.1177/1756285611417920.
18. Xu W, Jiang C, Yu C, et al. Percutaneous balloon compression for persistent or recurrent trigeminal neuralgia after microvascular decompression: personal experience of 28 patients. *Acta Neurol Belg* 2018; 118: 561–566. DOI: 10.1007/s13760-017-0858-8.
19. Tuleasca C, Carron R, Resseguier N, et al. Repeat Gamma Knife surgery for recurrent trigeminal neuralgia: long-term outcomes and systematic review. *J Neurosurg* 2014; 121 Suppl: 210–221. DOI: 10.3171/2014.8.GKS141487.
20. Abdel-Rahman KA, Elawamy AM, Mostafa MF, et al. Combined pulsed and thermal radiofrequency versus thermal radiofrequency alone in the treatment of recurrent trigeminal neuralgia after microvascular decompression: a double blinded comparative study. *Eur J Pain* 2020; 24: 338–345. DOI: 10.1002/ejp.1489.
21. Ko AL, Lee A, Raslan AM, et al. Trigeminal neuralgia without neurovascular compression presents earlier than trigeminal neuralgia with neurovascular compression. *J Neurosurg* 2015; 123: 1519–1527. DOI: 10.3171/2014.11.JNS141741.
22. Ko AL, Ozpinar A, Lee A, et al. Long-term efficacy and safety of internal neurolysis for trigeminal neuralgia without neurovascular compression. *J Neurosurg* 2015; 122: 1048–1057. DOI: 10.3171/2014.12.JNS14469.
23. Zhang X, Xu L, Zhao H, et al. Long-term efficacy of nerve combing for patients with trigeminal neuralgia and failed prior microvascular decompression. *World Neurosurg* 2017; 108: 711–715. 2017/09/26. DOI: 10.1016/j.wneu.2017.09.081.
24. Cheng J, Meng J, Lei D, et al. Repeat microvascular decompression for patients with persistent or recurrent trigeminal neuralgia: prognostic factors and long-term outcomes. *Medicine (Baltimore)* 2019; 98: e15167. DOI: 10.1097/MD.0000000000015167.
25. Hussain MA, Konteas A, Sunderland G, et al. Re-exploration of microvascular decompression in recurrent trigeminal neuralgia and intraoperative management options. *World Neurosurg* 2018; 117: e67–e74. DOI: 10.1016/j.wneu.2018.05.147.
26. Theodros D, Rory Goodwin C, Bender MT, et al. Efficacy of primary microvascular decompression versus subsequent microvascular decompression for trigeminal neuralgia. *J Neurosurg* 2017; 126: 1691–1697. 2016/07/16. DOI: 10.3171/2016.5.JNS151692.
27. Capelle H-H, Brandis A, Tschan CA, et al. Treatment of recurrent trigeminal neuralgia due to Teflon granuloma. *J Headache Pain* 2010; 11: 339–344. DOI: 10.1007/s10194-010-0213-4.
28. Wei Y, Pu C, Li N, et al. Long-term therapeutic effect of microvascular decompression for trigeminal neuralgia: Kaplan-Meier analysis in a consecutive series of 425 patients. *Turk Neurosurg* 2018; 28: 88–93. DOI: 10.5137/1019-5149.JTN.18322-16.1.
29. Bakker NA, Van Dijk JMC, Immenga S, et al. Repeat microvascular decompression for recurrent idiopathic trigeminal neuralgia. *J Neurosurg* 2014; 121: 936–939. DOI: 10.3171/2014.7.JNS132667.

30. Amador N and Pollock BE. Repeat posterior fossa exploration for patients with persistent or recurrent idiopathic trigeminal neuralgia. *J Neurosurg* 2008; 108: 916–920. DOI: 10.3171/JNS/2008/108/5/0916.
31. Patra DP, Savardekar AR, Dossani RH, et al. Repeat Gamma Knife radiosurgery versus microvascular decompression following failure of GKRS in trigeminal neuralgia: a systematic review and meta-analysis. *J Neurosurg* 2018: 1–10. 2018/11/30. DOI: 10.3171/2018.5.JNS18583.
32. Müller S, Khadhraoui E, Khanafer A, et al. Differentiation of arterial and venous neurovascular conflicts estimates the clinical outcome after microvascular decompression in trigeminal neuralgia. *BMC Neurol* 2020; 20: 279. 2020/07/16. DOI: 10.1186/s12883-020-01860-8.
33. Leal PRL, Hermier M, Souza MA, et al. Visualization of vascular compression of the trigeminal nerve with high-resolution 3T MRI: a prospective study comparing preoperative imaging analysis to surgical findings in 40 consecutive patients who underwent microvascular decompression for trigeminal neuralgia. *Neurosurgery* 2011; 69. DOI: 10.1227/NEU.0b013e318212bafa.