A Comparative Review of the Outcome Following MVD and PBC in Patients with Trigeminal Neuralgia

Yi Zhou[1,*] Ning-Ning Dou[2,*] Xue-Lai Liu[3] Hui Wang[1] Jun Zhong[2]

[1] Department of Neurosurgery, TaiHe Hospital, Hubei University of Medicine, Shiyan, Hubei, People's Republic of China
[2] Department of Neurosurgery, XinHua Hospital, Shanghai JiaoTong University School of Medicine, Shanghai, People's Republic of China
[3] Department of Neurosurgery, LingYi Hospital of Traditional Chinese Medicine, Shandong, People's Republic of China

Address for correspondence Jun Zhong, MD, PhD, Department of Neurosurgery, XinHua Hospital, Shanghai JiaoTong University School of Medicine, Shanghai 200092, People's Republic of China (e-mail: ZhongJun@XinHuaMed.com.cn).

J Neurol Surg A Cent Eur Neurosurg 2023;84:470–476.

Abstract

Background This study aims to systematically review the treatment outcomes of percutaneous balloon compression (PBC) and microvascular decompression (MVD) in patients with trigeminal neuralgia.

Methods A systematic review in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-analyses (PRISMA) guideline was performed using PubMed, Embase, and Cochrane Central Registry of Controlled Trials databases. Only those articles with more than 5 years' follow-up length were included in this investigation. To uniformly assess the postoperative outcome, we defined *pain relief* as totally pain free, while the postoperative hospitalization and last follow-up period were defined as *early* and *long term*, respectively. The facial numbness was quantified with Barrow Neurological Institute Pain Intensity Score (BNI).

Results After database searching and screening, 7,797 cases were finally included according to the criteria. The *early pain relief* rates were 94.1% (1,551/1,649) and 89.9% (4,962/5,482) following PBC and MVD (odds ratio [OR] = 0.603; $p < 0.05$), while the *long-term* rates were 58.1% (921/1,566) and 74.9% (4,549/6,074; OR = 2.089; $p < 0.05$), respectively. Although a significant higher facial numbness occurred in the PBC group in the early stage, it was mostly diminished 5 years later compared with the MVD group. At long-term follow-up, hypoacusis and facial palsy occurred more often in the MVD group ($p < 0.05$).

Conclusions Both MVD and PBC provide a satisfactory outcome for the patients in the long term. As a simple, safe, and reliable technique, PBC should be considered as a viable alternative.

Keywords
- trigeminal neuralgia
- microvascular decompression
- percutaneous balloon compression
- long-term

Introduction

Although it is not life-threatening, patients with trigeminal neuralgia (TN) suffer from an intense pain.[1] According to the American Academy of Neurology (AAN), the European Federation of Neurological Societies (EFNS), and also other recent guidelines, carbamazepine (CBZ) and oxcarbazepine (OXC) are the first-line medical treatments. These drugs are highly effective with meaningful pain control in almost 90% of patients.[2,3] However, clinical improvement is often offset

* *Drs Dou and Zhou contributed equally to this study.*

received
January 3, 2022
accepted after revision
December 5, 2022
accepted manuscript online
December 8, 2022
article published online
May 11, 2023

DOI https://doi.org/10.1055/a-1994-7956.
ISSN 2193-6315.

by side effects and treatment withdrawal in 23% of patients. Surgery is generally undertaken only when standard doses of medications are not sufficient to control symptoms or if side effects prevent continued use. The surgical processes can be catalogued as etiological and symptomatic managements. As a unique etiological treatment, the success of microvascular decompression (MVD) depends upon the reversibility of dysfunction caused by arterial compression of the nerve root.[4–6] However, MVD may not work in those with idiopathic TN (no apparent cause of nerve disturbance can be found).[7,8] Besides, not all the patients with classical TN are ready to accept the craniotomy. Therefore, those less invasive therapies, for example, Gamma Knife stereotactic radiosurgery, glycerol rhizotomy, and radiofrequency thermocoagulation as well as percutaneous balloon compression (PBC) have been still widely adopted.[9–12] Due to low cost, simplicity, and the advantage of thorough compression of the ganglion, PBC has been popularized recently—especially for the elderly patients, those with comorbidities who are not good craniotomy candidates and those with recurrence following MVD.[13]

Unlike the other symptomatic treatments acting on the axons, PBC targets the gasserian ganglion (neuron soma). With the unrenewable nature of neurons, an appropriate compression may result in an unrecoverable lesion and give rise to a permanent pain relief. Theoretically, it is possible to damage more pain-sensing than other neurons if appropriate pressure is applied due to the difference in resilience of varied neurons.

In this investigation, we conducted a systematical review to compare the cure, recurrence, and complication rates between PBC and MVD. We were able to obtain evidence to support the hypothesis that proper compression of the trigeminal ganglion may lead to a long-term pain-free outcome without permanent dysesthesia.

Material and Methods

Database Searching

Electronic searches were performed using Ovid Embase, PubMed, and Cochrane Central Register of Controlled Trials (CCTR) from their dates of inception to June 2021. The diagnostic terms used were as follows: trigeminal neuralgia, tic douloureux, and facial neuralgia. They were combined with the following surgical terms: rhizotomy, balloon compression, microcompression, percutaneous compression and microvascular decompression.

Inclusion Criteria and Identified Studies

The primary inclusion criterion for this investigation was the average follow-up duration of the studies, which should be more than 5 years. The identified studies were read in their full texts and evaluated for quality using a criterion reported by Zakrzewska and Lopez,[14] which had been established by a panel of 11 neurosurgeons and 2 neurologists who were members of the advisory boards of the United States or United Kingdom TN associations (►**Table 1**). Almost all patients underwent preoperative magnetic resonance (MR) examination. The possible neurovascular conflict (NCV) was investigated preoperatively by MR cranial nerve hydrographic imaging technique before MVD. In cases of studies reporting the same data or data involving more patients or longer follow-up monitoring, only the study with the largest patient number was used.

Table 1 Inclusion criteria

1. Study dealing with primary trigeminal neuralgia
2. Minimum of 30 patients treated in the whole series
3. Less than 10% of patients treated more than once with any procedure
4.Minimum of 5-year mean follow-up period
5. Diagnostic criteria stated
6. Definition of success presented
7. Definition of recurrence presented
8. Length of follow-up period with range and mean-median presented
9. Explicit definition of outcome measure used
10. Mortality rate stated
11. Report of perioperative complication
12. Report of postoperative complication

Note: The criterion of this table was a recommendation for outcome reporting for the surgical treatment of trigeminal neuralgia, established by a panel of 11 neurosurgeons and 2 neurologists, who were members of the advisory boards of the United States or United Kingdom trigeminal neuralgia associations.[14]

Outcome Evaluation

To properly assess the postoperative outcome, total relief from pain without any medication in the postoperative course was defined as *pain relief*, while recurrence of pain not adequately controlled by medication was defined as *recurrence*. Meanwhile, we defined the postoperative hospitalization period as *early-term* and a more than 5 years' follow-up period as *long term*, respectively. Furthermore, we regarded the complications that emerged within 6 months postoperatively as *transient*, while those that existed persistently during the whole follow-up period were regarded as *permanent*. In the selected articles, facial numbness was depicted as hypesthesia, paresthesia, and dysesthesia. In the study, we categorized the numbness with Barrow Neurological Institute Pain Intensity Score (BNI). BNI I is defined as no numbness, BNI II as moderate numbness that has no impact on daily life, BNI III as numbness that somewhat exerts an impact on daily life, and BNI IV as numbness that has a serious impact on daily life.[15]

Data Analysis

The following variables were recorded in a predesigned database: general information (author, year, surgery period, sample size, treatment success [before discharge and overall; ►**Table 2**], follow-up duration, and adverse events including facial numbness, hearing deficit, cerebrospinal fluid (CSF) leak, diminished corneal reflex, aseptic

Table 2 List of the included studies

Study	Country	Period	Technique	Mean FU (mo)	No. (male%)	Comp-Time (min)
Bederson et al[17]	United States	1969–1985	MVD	61	76 (30.2)	
Lichtor et al[18]	United States	1980–1990	PBC	120	–	3–5
Sun et al[19]	Japan	1982–1992	MVD	80	61 (32.8)	–
Walchenbach et al[20]	Netherlands	1980–1990	MVD	77.3	19 (32.2)	–
Barker FN et al[21]	United States	1972–1991	MVD	74	479 (40)	–
Skirving et al[22]	Australia	1980–1999	PBC	128	496 (56.3)	2–5
Tyler-Kabara et al[23]	United States	1972–2000	MVD	125	883 (39)	–
Sindou et al[24]	France	1983–1999	MVD	86	–	–
Laghmari et al[25]	Morocco	1983–2004	PBC/MVD	72	41 (51.2)	5
Ferroli et al[26]	Italy	1997–2007	MVD	70	476 (–)	–
Günther et al[27]	Germany	1979–2001	MVD	90	362 (–)	–
Sarsam et al[28]	England	1982–2005	MVD	84	123 (38.5)	–
Oesman et al[29]	England	1983–2003	MVD	114	66 (42)	–
Chen et al[30]	China	2000–2010	PBC	120	63 (48.5)	2–3
Zhang et al[31]	China	2001–2011	MVD	67	56 (36)	–
Abdennebi et al[32]	Algeria	1985–2012	PBC	198	901 (47.2)	7
Sandel et al[33]	Norway	1999–2009	MVD	85	98 (40.3)	–
Masuoka et al[34]	Japan	2007–2012	MVD	62	50 (30)	–
Liu et al[35]	China	2009–2017	MVD	63	30 (30.3)	–

Abbreviations: Comp-Time, compression time; FU, follow-up; mo, month; MVD, microvascular decompression; No., patient number; PBC, percutaneous balloon compression.

meningitis, and mortality). Statistical analysis was performed using the IBM SPSS 26 (IBM Analytics, Armonk, New York, United States) software, with a significance level of $p < 0.05$ for all tests. The two-sided chi-squared test or Fisher's exact test was used to compare proportions between groups of patients. Data were censored if there was no pain recurrence at the most recent follow-up.

Results

Study Identification

A total of 1,676 articles were systematically assessed (1,388, 258, and 30 refer to MVD, PBC, and both, respectively). According to the inclusion criteria, 1,033 were excluded following title and abstract screening and 502 studies were subjected to a full-text review.[16] Finally, 19 articles[17–35] consisting of 7,797 cases met the predetermined search criteria and were included in this study (►**Fig. 1**)

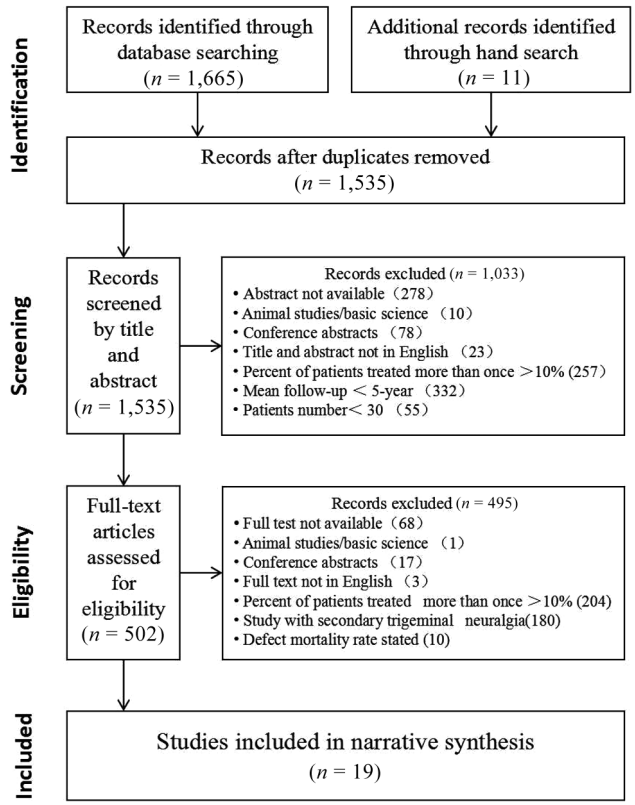

Fig. 1 A flowchart regarding the literature search and study selection.

Outcomes

Pain Relief

The incidences of early pain relief were 94.1% (1,551/1,649) and 89.9% (4,962/5,482) following PBC and MVD, respectively (odds ratio [OR] = 0.603; 95% confidence interval [CI]: 0.482–0.754; $p < 0.05$). The long-term pain relief rates were 58.1% (921/1,566) and 74.9% (4,549/6,074; PBC vs. MVD; OR = 2.089; 95% CI = 1.860–2.346; $p < 0.05$; ►**Table 3**).

Table 3 Outcome comparison between PBC and MVD

Outcome	PBC	MVD	*p* value
Early pain relief	94.1% (1,551/1,649)	89.9% (4,962/5,482)	<0.05
Long-term pain relief	58.1% (921/1,566)	74.9% (4,549/6,074)	<0.05
Recurrence	39.2% (614/1,566)	18.9% (1,144/6,074)	<0.05

Abbreviations: MVD, microvascular decompression; PBC, percutaneous balloon compression.
Note: Values are presented as rate (number).

Recurrence

The recurrence rates within the entire follow-up period were 39.2% (614/1,566) and 18.9% (1,144/6,074) in the PBC and MVD groups, respectively (OR = 0.360; 95% CI = 0.319–0.406; $p < 0.05$; ►**Table 3**).

Complications

The most prominent difference in complications between the PBC and MVD groups were facial numbness. In the early stage following PBC and MCD, the facial numbness BNI II occurred in 83.3% (1,374/1,649) and 2.1% (103/4,908), BNI III in 11.2 and 0.3%, BNI IV in 2.4 and 0.5%, respectively. At the last follow-up, BNI II occurred in 1.9% (32/1,649) and 1.0% (26/4,908), BNI III in 1.0 and 0.2%, and BNI IV in 1.9 and 0.1%, respectively. Other transient complications included herpes, nerve palsy, infection, rhinorrhea and vertigo, and CSF fistula, which mainly occurred in MVD groups (►**Table 4**). The other long-term complications, such as hypacusis and facial palsy, occurred more often in the MVD group (►**Table 5**). The percentage of surgical mortality was 0.1% (1/1,649) and 0.1% (9/6,074) in the PBC and MVD groups, respectively.

Table 4 Comparison of transient complications between PBC and MVD

Transient complications	PBC (%)	MVD (%)	*p* value
Facial numbness			
BNI I	3.1	97.1	<0.05
BNI II	83.3	2.1	<0.05
BNI III	11.2	0.3	<0.05
BNI IV	2.4	0.5	<0.05
Masticatory weakness	6.7	0.1	<0.05
Herpes	6.3	0.2	<0.05
Nerve palsies	1.3	2.7	>0.05
CSF fistula	0.2	2.0	<0.05
Infectious	0.1	0.7	>0.05
Vertigo	0.0	1.4	<0.05
Diminished corneal reflex	0.7	0.1	<0.05
Aseptic meningitis	0.1	22.4	<0.05

Abbreviations: BNI, Barrow Neurological Institute Pain Intensity Score; CSF, cerebrospinal fluid; MVD, microvascular decompression; PBC, percutaneous balloon compression.

Discussion

To date, results on the curative effect of MVD versus PBC for TN are inconsistent.[36,37] Previous researches that have been conducted to compare MVD and PBC included inhad small sample sizes.[38,39] This study systematically reviewed a long-term effect of PBC or MVD on treatment of TN. To objectively estimate the data collected from different studies, a uniform inclusion criterion is essential. In this investigation, a widely acceptable criterion, recommended by the Medical Advisory Board of the United States and United Kingdom Trigeminal Neuralgia Support Group, was adopted and 7,797 cases were included eventually.[14] Statistical analysis demonstrated that PBC gave rise to a significantly higher odds for early pain relief than MVD did. While a lower recurrence was found in MVD group, a relief rate close to 70% remained in the PBC group even 5 years later. The results implied that PBC could be a good alternative therapy compared with MVD.

Over the last decades, MVD has been regarded as an effective etiological treatment of classical TN, even in elderly patients,[40,41] because of its high cure and low relapse rate as well as the character of a nondestructive surgical technique.[21,28,31,42] The nerve can be compressed either by a vein or an artery or both somewhere along its intradural course. Sometimes, no compressing vessel can be found.[6,10,25,41–43] To ensure cure, some surgeons perform

Table 5 Comparison of permanent complications between PBC and MVD

Permanent complications	PBC (%)	MVD (%)	*p* value
Unilateral blindness	0.1	0.0	>0.05
Hearing loss	0.1	1.3	<0.05
Facial palsy	0.2	0.3	<0.05
Cerebral infarction	0.1	0.7	>0.05
Facial numbness			
BNI I	95.2	98.7	>0.05
BNI II	1.9	1.0	<0.05
BNI III	1.0	0.2	<0.05
BNI IV	1.9	0.1	<0.05
Mortality	0.1	0.1	>0.05

Abbreviations: BNI, Barrow Neurological Institute Pain Intensity Score; MVD, microvascular decompression; PBC, percutaneous balloon compression.

an "MVD plus" surgery, decompression followed by a partial sensory rhizotomy.[6,26,44–46] This operation may lead to facial numbness postoperatively. In conclusion, MVD is not the perfect therapy for TN so far.

In addition to MVD, a variety of ablative procedures are available. They all work more or less at a cost of hemifacial numbness.[47,48] Studies reported that radiofrequency thermal rhizotomy provided a similar initial pain relief rate as PBC.[49–52] However, this procedure relies on the patient's cooperation to localize the target—an awake surgery leaves the patient a painful and terrified experience. In contrast to the immediate pain relief associated with these percutaneous lesion processes, the pain-relieving effect of Gamma Knife stereotactic radiosurgery takes 6 to 8 weeks to develop.[4,53–55]

All destructive techniques except PBC target the axons,[56–58] which have higher rate of recovery, increasing the risk of recurrence.[59,60] PBC evenly compresses the structures of the trigeminal ganglion.[61–63] The ganglion consist of neuron somata, which cannot regenerate once destroyed. Theoretically, an appropriate compression may selectively damage the pain-sensing neurons and preserve others as far as possible. Nevertheless, the usual explanation is that compression injures the medium and large myelinated nerve fibers and led to disruption of the ephaptic transmission of pain. Notably, activity in myelinated sensory axons is generally associated with the sense of touch and vibration, not pain.[64,65] Injury of the myelinated nerve fiber is not closely related to pain relief. The overwhelming majority of studies reported that hemifacial numbness after PBC was usually transient and resolved spontaneously.[66] Although no trigger is eliminated in PBC, it virtually "powers off" the trigeminal nerve for the generation and conduction of action potentials depend on the energy support provide by the neurons. That is probably the reason why PBC leads to an immediately higher pain relief rate than MVD does. Therefore, we believe that if the gasserian ganglion have been compressed efficiently by a balloon inflated exactly inside Meckel's cave instead of in its interlay, a higher long-term efficacy can be expected.[67–69]

Regardless of the unavoidable facial numbness, the postoperative course was more even and comfortable in patients who underwent PBC than MVD.[70] Furthermore, the numbness rate can be reduced by a proper control of the compression time.[30,71] Lichtor and Mullan compared their first 60 patients with 5- to 7-minute compressions to the rest of the 40 patients with 1-minute compressions and found that the efficiency was the same and facial numbness rate was lower in the second group.[18] Evidently, there is a delicate balance between pain recurrence and numbness.[72,73] Referring to the literature, we believe a 1-minute compression might be adequate to achieve a pain-free outcome without apparent facial discomfort.[18,74,75]

Several limitations need to be considered. Although thousands of cases were included, they were drawn from different centers with diverse evaluation scales. Especially concerning numbness, it was delineated as hypesthesia, paresthesia, or dysesthesia in various studies. For standardization, we employed the BNI score to quantify the numbness in this investigation.

Conclusions

MVD could not cure all the patients, especially not those without an obvious compressing artery. In contrast, PBC may relieve TN symptoms in most cases as long as the trigeminal ganglion has been effectively compressed. As a simple, convenient, safe, and reliable alternative, PBC should be considered as a viable alternative.

Author Contributions

J.Z. contributed to the study conception and design. Material preparation, data collection, and analysis were performed by N.N.D., X.L.L., Y.Z. and H.W. The first draft of the manuscript was written by Y.Z., and all the authors commented on previous versions of the manuscript. All the authors read and approved the final manuscript.

Funding

None.

Conflict of Interest

None declared.

References

1 Cruccu G, Finnerup NB, Jensen TS, et al. Trigeminal neuralgia: new classification and diagnostic grading for practice and research. Neurology 2016;87(02):220–228
2 Headache Classification Committee of the International Headache Society (IHS) The International Classification of Headache Disorders, 3rd edition. Cephalalgia 2018;38(01):1–211
3 Di Stefano G, La Cesa S, Truini A, Cruccu G. Natural history and outcome of 200 outpatients with classical trigeminal neuralgia treated with carbamazepine or oxcarbazepine in a tertiary centre for neuropathic pain. J Headache Pain 2014;15(01):34
4 Jannetta PJ. Arterial compression of the trigeminal nerve at the pons in patients with trigeminal neuralgia. 1967. J Neurosurg 2007;107(01):216–219
5 Panczykowski DM, Jani RH, Hughes MA, Sekula RF. Development and evaluation of a preoperative trigeminal neuralgia scoring system to predict long-term outcome following microvascular decompression. Neurosurgery 2020;87(01):71–79
6 Zhong J, Zhu J, Sun H, et al. Microvascular decompression surgery: surgical principles and technical nuances based on 4000 cases. Neurol Res 2014;36(10):882–893
7 Hai J, Li ST, Pan QG. Treatment of atypical trigeminal neuralgia with microvascular decompression. Neurol India 2006;54(01): 53–56, discussion 57
8 Maarbjerg S, Gozalov A, Olesen J, Bendtsen L. Concomitant persistent pain in classical trigeminal neuralgia: evidence for different subtypes. Headache 2014;54(07):1173–1183
9 Jawahar A, Wadhwa R, Berk C, et al. Assessment of pain control, quality of life, and predictors of success after gamma knife surgery for the treatment of trigeminal neuralgia. Neurosurg Focus 2005;18(05):E8
10 Kouzounias K, Lind G, Schechtmann G, Winter J, Linderoth B. Comparison of percutaneous balloon compression and glycerol rhizotomy for the treatment of trigeminal neuralgia. J Neurosurg 2010;113(03):486–492

11 Lopez BC, Hamlyn PJ, Zakrzewska JM. Systematic review of ablative neurosurgical techniques for the treatment of trigeminal neuralgia. Neurosurgery 2004;54(04):973–982, discussion 982–983
12 Maesawa S, Salame C, Flickinger JC, Pirris S, Kondziolka D, Lunsford LD. Clinical outcomes after stereotactic radiosurgery for idiopathic trigeminal neuralgia. J Neurosurg 2001;94(01): 14–20
13 Mullan S, Lichtor T. Percutaneous microcompression of the trigeminal ganglion for trigeminal neuralgia. J Neurosurg 1983;59 (06):1007–1012
14 Zakrzewska JM, Lopez BC. Quality of reporting in evaluations of surgical treatment of trigeminal neuralgia: recommendations for future reports. Neurosurgery 2003;53(01):110–120, discussion 120–122
15 Rogers CL, Shetter AG, Fiedler JA, Smith KA, Han PP, Speiser BL. Gamma knife radiosurgery for trigeminal neuralgia: the initial experience of the Barrow Neurological Institute. Int J Radiat Oncol Biol Phys 2000;47(04):1013–1019
16 Moher D, Liberati A, Tetzlaff J, Altman DGPRISMA Group. Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. BMJ 2009;339:b2535
17 Bederson JB, Wilson CB. Evaluation of microvascular decompression and partial sensory rhizotomy in 252 cases of trigeminal neuralgia. J Neurosurg 1989;71(03):359–367
18 Lichtor T, Mullan JF. A 10-year follow-up review of percutaneous microcompression of the trigeminal ganglion. J Neurosurg 1990; 72(01):49–54
19 Sun T, Saito S, Nakai O, Ando T. Long-term results of microvascular decompression for trigeminal neuralgia with reference to probability of recurrence. Acta Neurochir (Wien) 1994;126(2–4):144–148
20 Walchenbach R, Voormolen JH, Hermans J. Microvascular decompression for trigeminal neuralgia: a critical reappraisal. Clin Neurol Neurosurg 1994;96(04):290–295
21 Barker FG II, Jannetta PJ, Bissonette DJ, Larkins MV, Jho HD. The long-term outcome of microvascular decompression for trigeminal neuralgia. N Engl J Med 1996;334(17):1077–1083
22 Skirving DJ, Dan NG. A 20-year review of percutaneous balloon compression of the trigeminal ganglion. J Neurosurg 2001;94(06): 913–917
23 Tyler-Kabara EC, Kassam AB, Horowitz MH, et al. Predictors of outcome in surgically managed patients with typical and atypical trigeminal neuralgia: comparison of results following microvascular decompression. J Neurosurg 2002;96(03):527–531
24 Sindou M, Leston J, Howeidy T, Decullier E, Chapuis F. Microvascular decompression for primary trigeminal neuralgia (typical or atypical). Long-term effectiveness on pain; prospective study with survival analysis in a consecutive series of 362 patients. Acta Neurochir (Wien) 2006;148(12):1235–1245, discussion 1245
25 Laghmari M, El Ouahabi A, Arkha Y, Derraz S, El Khamlichi A. Are the destructive neurosurgical techniques as effective as microvascular decompression in the management of trigeminal neuralgia? Surg Neurol 2007;68(05):505–512
26 Ferroli P, Acerbi F, Tomei M, Tringali G, Franzini A, Broggi G. Advanced age as a contraindication to microvascular decompression for drug-resistant trigeminal neuralgia: evidence of prejudice? Neurol Sci 2010;31(01):23–28
27 Günther T, Gerganov VM, Stieglitz L, Ludemann W, Samii A, Samii M. Microvascular decompression for trigeminal neuralgia in the elderly: long-term treatment outcome and comparison with younger patients. Neurosurgery 2009;65(03):477–482, discussion 482
28 Sarsam Z, Garcia-Fiñana M, Nurmikko TJ, Varma TR, Eldridge P. The long-term outcome of microvascular decompression for trigeminal neuralgia. Br J Neurosurg 2010;24(01):18–25
29 Oesman C, Mooij JJ. Long-term follow-up of microvascular decompression for trigeminal neuralgia. Skull Base 2011;21(05): 313–322
30 Chen JF, Tu PH, Lee ST. Long-term follow-up of patients treated with percutaneous balloon compression for trigeminal neuralgia in Taiwan. World Neurosurg 2011;76(06):586–591
31 Zhang H, Lei D, You C, Mao BY, Wu B, Fang Y. The long-term outcome predictors of pure microvascular decompression for primary trigeminal neuralgia. World Neurosurg 2013;79(5–6):756–762
32 Abdennebi B, Guenane L. Technical considerations and outcome assessment in retrogasserian balloon compression for treatment of trigeminal neuralgia. Series of 901 patients. Surg Neurol Int 2014;5:118
33 Sandel T, Eide PK. Long-term results of microvascular decompression for trigeminal neuralgia and hemifacial spasms according to preoperative symptomatology. Acta Neurochir (Wien) 2013;155 (09):1681–1692, discussion 1692
34 Masuoka J, Matsushima T, Inoue K, Nakahara Y, Takase Y, Kawashima M. Outcome of microvascular decompression for trigeminal neuralgia treated with the stitched sling retraction technique. Neurosurg Rev 2015;38(02):361–365, discussion 365
35 Liu R, Deng Z, Zhang L, Liu Y, Wang Z, Yu Y. 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
36 Texakalidis P, Xenos D, Tora MS, Wetzel JS, Boulis NM. Comparative safety and efficacy of percutaneous approaches for the treatment of trigeminal neuralgia: a systematic review and meta-analysis. Clin Neurol Neurosurg 2019;182:112–122
37 Maarbjerg S, Gozalov A, Olesen J, Bendtsen L. Trigeminal neuralgia: a prospective systematic study of clinical characteristics in 158 patients. Headache 2014;54(10):1574–1582
38 Gubian A, Rosahl SK. Meta-analysis on safety and efficacy of microsurgical and radiosurgical treatment of trigeminal neuralgia. World Neurosurg 2017;103:757–767
39 Sharma R, Phalak M, Katiyar V, Borkar S, Kale SS, Mahapatra AK. Microvascular decompression versus stereotactic radiosurgery as primary treatment modality for trigeminal neuralgia: a systematic review and meta-analysis of prospective comparative trials. Neurol India 2018;66(03):688–694
40 Sekula RF, Marchan EM, Fletcher LH, Casey KF, Jannetta PJ. Microvascular decompression for trigeminal neuralgia in elderly patients. J Neurosurg 2008;108(04):689–691
41 Sekula RF Jr, Frederickson AM, Jannetta PJ, Quigley MR, Aziz KM, Arnone GD. Microvascular decompression for elderly patients with trigeminal neuralgia: a prospective study and systematic review with meta-analysis. J Neurosurg 2011;114(01):172–179
42 Ashkan K, Marsh H. Microvascular decompression for trigeminal neuralgia in the elderly: a review of the safety and efficacy. Neurosurgery 2004;55(04):840–848, discussion 848–850
43 Gusmão S, Oliveira M, Tazinaffo U, Honey CR. Percutaneous trigeminal nerve radiofrequency rhizotomy guided by computerized tomography fluoroscopy. Technical note. J Neurosurg 2003; 99(04):785–786
44 Bigder MG, Krishnan S, Cook EF, Kaufmann AM. Microsurgical rhizotomy for trigeminal neuralgia in MS patients: technique, patient satisfaction, and clinical outcomes. J Neurosurg 2018;18 (06):1877–1888
45 Kondziolka D, Lunsford LD. Percutaneous retrogasserian glycerol rhizotomy for trigeminal neuralgia: technique and expectations. Neurosurg Focus 2005;18(05):E7
46 Zhong J, Li ST, Xu SQ, Wan L, Wang X. Management of petrosal veins during microvascular decompression for trigeminal neuralgia. Neurol Res 2008;30(07):697–700
47 Lovely TJ. Efficacy and complications of microvascular decompression: a review. Neurosurg Q 1998;8(02):92–106

48 Brown JA, McDaniel MD, Weaver MT. Percutaneous trigeminal nerve compression for treatment of trigeminal neuralgia: results in 50 patients. Neurosurgery 1993;32(04):570–573
49 Jia DZ, Li G. Bioresonance hypothesis: a new mechanism on the pathogenesis of trigeminal neuralgia. Med Hypotheses 2010;74 (03):505–507
50 Kanpolat Y, Savas A, Bekar A, Berk C. Percutaneous controlled radiofrequency trigeminal rhizotomy for the treatment of idiopathic trigeminal neuralgia: 25-year experience with 1,600 patients. Neurosurgery 2001;48(03):524–532, discussion 532–534
51 Nugent GR. Radiofrequency treatment of trigeminal neuralgia using a cordotomy-type electrode. A method. Neurosurg Clin N Am 1997;8(01):41–52
52 Pollock BE, Phuong LK, Foote RL, Stafford SL, Gorman DA. High-dose trigeminal neuralgia radiosurgery associated with increased risk of trigeminal nerve dysfunction. Neurosurgery 2001;49(01): 58–62, discussion 62–64
53 Dos Santos MA, Pérez de Salcedo JB, Gutiérrez Diaz JA, et al. Outcome for patients with essential trigeminal neuralgia treated with linear accelerator stereotactic radiosurgery. Stereotact Funct Neurosurg 2011;89(04):220–225
54 Inoue T, Hirai H, Shima A, et al. Long-term outcomes of microvascular decompression and Gamma Knife surgery for trigeminal neuralgia: a retrospective comparison study. Acta Neurochir (Wien) 2017;159(11):2127–2135
55 Oh IH, Choi SK, Park BJ, Kim TS, Rhee BA, Lim YJ. The treatment outcome of elderly patients with idiopathic trigeminal neuralgia : micro-vascular decompression versus Gamma Knife radiosurgery. J Korean Neurosurg Soc 2008;44(04):199–204
56 Gambeta E, Chichorro JG, Zamponi GW. Trigeminal neuralgia: an overview from pathophysiology to pharmacological treatments. Mol Pain 2020;16:1–18
57 Ghurye S, McMillan R. Orofacial pain: an update on diagnosis and management. Br Dent J 2017;223(09):639–647
58 Rappaport HZ, Devor M. Trigeminal neuralgia: the role of self-sustaining discharge in the trigeminal ganglion. Pain 1994;56 (02):127–138
59 Liu M, Zhong J, Xia L, Dou N, Li S. The expression of voltage-gated sodium channels in trigeminal nerve following chronic constriction injury in rats. Int J Neurosci 2019;129(10):955–962
60 Liu MX, Zhong J. Mechanism underlying cranial nerve rhizopathy. Med Hypotheses 2020;142:109801.10.1016
61 Araya EI, Claudino RF, Piovesan EJ, Chichorro JG. Trigeminal neuralgia: basic and clinical aspects. Curr Neuropharmacol 2020;18(02):109–119
62 Khodashenas M, Baghdadi G, Towhidkhah F. A modified Hodgkin-Huxley model to show the effect of motor cortex stimulation on the trigeminal neuralgia network. J Math Neurosci 2019;9(01):4
63 Kumar S, Rastogi S, Kumar S, Mahendra P, Bansal M, Chandra L. Pain in trigeminal neuralgia: neurophysiology and measurement: a comprehensive review. J Med Life 2013;6(04):383–388
64 Brown JA, Hoeflinger B, Long PB, et al. Axon and ganglion cell injury in rabbits after percutaneous trigeminal balloon compression. Neurosurgery 1996;38(05):993–1003, discussion 1003–1004
65 Preul MC, Long PB, Brown JA, Velasco ME, Weaver MT. Autonomic and histopathological effects of percutaneous trigeminal ganglion compression in the rabbit. J Neurosurg 1990;72(06):933–940
66 Devor M, Amir R, Rappaport ZH. Pathophysiology of trigeminal neuralgia: the ignition hypothesis. Clin J Pain 2002;18(01):4–13
67 Liu HB, Ma Y, Zou JJ, Li XG. Percutaneous microballoon compression for trigeminal neuralgia. Chin Med J (Engl) 2007;120(03): 228–230
68 Lobato RD, Rivas JJ, Sarabia R, Lamas E. Percutaneous microcompression of the gasserian ganglion for trigeminal neuralgia. J Neurosurg 1990;72(04):546–553
69 Omeis I, Smith D, Kim S, Murali R. Percutaneous balloon compression for the treatment of recurrent trigeminal neuralgia: long-term outcome in 29 patients. Stereotact Funct Neurosurg 2008;86(04):259–265
70 Spatz AL, Zakrzewska JM, Kay EJ. Decision analysis of medical and surgical treatments for trigeminal neuralgia: how patient evaluations of benefits and risks affect the utility of treatment decisions. Pain 2007;131(03):302–310
71 Kouzounias K, Schechtmann G, Lind G, Winter J, Linderoth B. Factors that influence outcome of percutaneous balloon compression in the treatment of trigeminal neuralgia. Neurosurgery 2010;67(04):925–934, discussion 934
72 Lee ST, Chen JF. Percutaneous trigeminal ganglion balloon compression for treatment of trigeminal neuralgia—part I: pressure recordings. Surg Neurol 2003;59(01):63–66, discussion 66–67
73 Lee ST, Chen JF. Percutaneous trigeminal ganglion balloon compression for treatment of trigeminal neuralgia, part II: results related to compression duration. Surg Neurol 2003;60(02):149–153, discussion 153–154
74 Park SS, Lee MK, Kim JW, Jung JY, Kim IS, Ghang CG. Percutaneous balloon compression of trigeminal ganglion for the treatment of idiopathic trigeminal neuralgia : experience in 50 patients. J Korean Neurosurg Soc 2008;43(04):186–189
75 Unal TC, Unal OF, Barlas O, et al. Factors determining the outcome in trigeminal neuralgia treated with percutaneous balloon compression. World Neurosurg 2017;107:69–74