www.surgicalneurologyint.com

ScientificScholar® Knowledge is power
Publisher of Scientific Journals

Surgical Neurology International

Editor-in-Chief: Nancy E. Epstein, MD, Professor of Clinical Neurosurgery, School of Medicine, State U. of NY at Stony Brook.

SNI: Neuroanatomy and Neurophysiology

Editor
Seyed Ali Khonsary, MD
University of California at Los Angeles, Los Angeles, CA, USA

SNI
Open Access

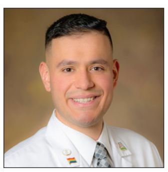
Review Article

Awake neurosurgery: Advancements in microvascular decompression for trigeminal neuralgia

Areeba Fareed[1,2], Zoha Iftikhar[1,2], Ramsha Haider[1,2], Safa Irfan Shah[1,2], Michelle Ennabe[1,3], Albert Alan[1,4,5], Martin Weinand[4,5]

[1]Global Neurosurgical Alliance, Tucson, Arizona, USA, [2]Karachi Medical and Dental College, Karachi, Pakistan, [3]College of Medicine, The University of Arizona College of Medicine-Phoenix, [4]College of Medicine, The University of Arizona College of Medicine-Tucson, [5]Department of Neurosurgery, University of Arizona, Tucson, Arizona, USA.

E-mail: Areeba Fareed - areebafareed201@gmail.com; Zoha Iftikhar - zohaiftikhar7@gmail.com; Ramsha Haider - ramshahaider521@gmail.com; Safa Irfan Shah - safashah458@gmail.com; Michelle Ennabe - mennabe@arizona.edu; *Albert Alan - albertalan@arizona.edu; Martin Weinand - mweinand@arizona.edu



***Corresponding author:**
Albert Alan,
Department of Neurosurgery,
University of Arizona, Tucson,
Arizona, United States.

albertalan@arizona.edu

Received: 12 April 2024
Accepted: 24 April 2024
Published: 28 June 2024

DOI
10.25259/SNI_286_2024

Quick Response Code:

ABSTRACT

Background: The treatment landscape for trigeminal neuralgia (TN) involves various surgical interventions, among which microvascular decompression (MVD) stands out as highly effective. While MVD offers significant benefits, its success relies on precise surgical techniques and patient selection. In addition, the emergence of awake surgery techniques presents new opportunities to improve outcomes and minimize complications associated with MVD for TN.

Methods: A thorough review of the literature was conducted to explore the effectiveness and challenges of MVD for TN, as well as the impact of awake surgery on its outcomes. PubMed and Medline databases were searched from inception to March 2024 using specific keywords "Awake Neurosurgery," "Microvascular Decompression," AND "Trigeminal Neuralgia." Studies reporting original research on human subjects or preclinical investigations were included in the study.

Results: This review highlighted that MVD emerges as a highly effective treatment for TN, offering long-term pain relief with relatively low rates of recurrence and complications. Awake surgery techniques, including awake craniotomy, have revolutionized the approach to MVD, providing benefits such as reduced postoperative monitoring, shorter hospital stays, and improved neurological outcomes. Furthermore, awake MVD procedures offer opportunities for precise mapping and preservation of critical brain functions, enhancing surgical precision and patient outcomes.

Conclusion: The integration of awake surgery techniques, particularly awake MVD, represents a significant advancement in the treatment of TN. Future research should focus on refining awake surgery techniques and exploring new approaches to optimize outcomes in MVD for TN.

Keywords: Awake craniotomy, Awake surgery, Microvascular decompression, Surgical precision, Trigeminal neuralgia

INTRODUCTION

Trigeminal neuralgia (TN), or tic douloureux, is a neurological disorder that causes sudden and intense pain in the trigeminal nerve distribution. The pain usually lasts a few seconds to a few minutes and is triggered by sensory stimuli or specific facial movements.[36] This condition is more common among women aged between 37 and 67 years and mainly affects the maxillary and mandibular branches of the trigeminal nerve.[11] TN is commonly addressed with medications, each with distinct side effects and effectiveness. Traditional first-line anticonvulsants such as carbamazepine and oxcarbazepine offer significant immediate pain relief.[48] However, their long-term efficacy may decline, necessitating higher doses or additional medications. These anticonvulsants can induce side effects such as dizziness, drowsiness, cognitive impairment, and liver toxicity.[10] Alternatives for long-term management include medications such as lamotrigine, gabapentin, botulinum toxin type A, pregabalin, baclofen, and phenytoin, either alone or in combination. Gabapentin and baclofen, which modulate calcium channels and act as a γ-aminobutyric acid agonist, respectively, show promise in alleviating TN symptoms. In addition, botulinum toxin type A, typically used for cosmetic purposes, presents as a potential TN treatment by inhibiting acetylcholine release from nerve terminals, thereby reducing pain signal transmission.[41] Over time, the frequency, duration, and intensity of pain attacks tend to increase, and may become resistant to medication. As a result, the condition can become chronic, significantly reducing the quality of life for those affected and leading to cognitive impairments such as anxiety and depression.[35,44]

Microvascular decompression (MVD) stands as the pinnacle of surgical intervention for classic TN, earning its reputation as the "gold standard" procedure. MVD involves meticulous exploration using microscopes or endoscopes to identify and alleviate compression on the trigeminal nerve caused by adjacent blood vessels or structures. A crucial aspect of MVD entails placing a cushioning material between the compressing vessel and the trigeminal nerve root to alleviate the pressure and subsequent pain.[36]

Studies conducted across multiple centers have consistently demonstrated the safety and efficacy of MVD in providing relief to TN patients. Pain relief rates following MVD have been reported to range impressively from 80% to 96%, highlighting its effectiveness in managing TN-associated facial pain.[23,47] Despite advancements in surgical techniques, TN remains a challenging condition to manage. While primary surgical interventions like MVD exhibit promising efficacy, long-term success rates may diminish. Approximately 75% of patients achieve pain freedom at the 2-year mark post-MVD, yet, this figure gradually declines to 44–64% by the 10th year.[23,46] Furthermore, alternative surgical modalities such as stereotactic radiosurgery (SRS) may be considered, although with lower long-term success rates (38.8% vs. 52.8%) at 7 years follow-up compared to MVD, necessitating continued exploration for optimal management strategies.[5]

The advent of awake surgery presents a notable advancement in the field of MVD. Awake MVD offers several advantages, including real-time patient feedback during the procedure, confirming the effectiveness of decompression, and minimizing risks associated with general anesthesia, particularly in vulnerable patient populations. During awake MVD, patients are typically under local anesthesia with sedation, allowing neurosurgeons to interact with them throughout the procedure. This facilitates immediate feedback on any changes in symptoms, ensuring precise and tailored intervention to address TN-associated pain effectively.[2] The objective of this review is to investigate awake MVD as a treatment for TN. Evaluating the efficacy of this intervention is essential for mitigating the effects of TN and improving patient outcomes. By thoroughly analyzing the available literature, the review aims to provide a detailed summary of the strengths and weaknesses of this approach and its potential implementation in clinical practice.

MATERIALS AND METHODS

A comprehensive review of the literature was carried out on PubMed and Medline databases, focusing on studies exploring the application of terms such as "Awake Neurosurgery," "Awake craniotomy," "Conscious sedation," along with "Microvascular Decompression," and "Trigeminal Neuralgia." Only complete manuscripts reporting original studies involving human subjects or preclinical research and published until 2023, were considered for inclusion.

BRIEF HISTORY OF MVD

In 1934, Dr. Walter E. Dandy discovered that compression on the trigeminal nerve root was caused by a superior cerebellar artery (SCA) loop in 30.7% of cases and by a branch of the petrosal vein in 14% of cases.[11,12,27] However, he acknowledged that the surgical exposure of the day may not have provided an appropriate visualization of other compressive lesions that were not yet identified. In addition, Dandy did not distinguish between pulsatile and static compression nor take into account the possibility that mobilizing the responsible vessel away from the underlying nerve could play a part in tic douloureux.[12,27] Taarnhøj proposed an alternative procedure to decompress the trigeminal nerve root at the porus trigeminus.[45]

In 1959, Dr. W. James Gardner and his colleagues adopted this approach and conducted a study on the decompression of the sensory root of the trigeminal nerve. They accomplished this by selectively sectioning the posterior lateral part of the nerve. The study found that this approach resulted in significant improvement in pain relief for patients suffering from TN.[15,38] Although later refined and popularized by others, Gardner's technique aimed to relieve pressure on the trigeminal nerve caused by vascular compression. For those with severe TN who are unresponsive to traditional therapies, this method marked a significant breakthrough.[38] Furthermore, Gardner expanded on Dandy's findings by emphasizing how important it is to recognize and treat vascular compressions, like arterial loops, as the underlying causes of TN.[39] Gardner's pioneering work remains foundational in the treatment of this condition especially those whose symptoms were uncontrollably refractory to treatment.[38] Building on the foundational contributions of Dr. W. James Gardner, Dr. Robert Rand, a distinguished neurosurgeon at the University of California Los Angeles, in collaboration with his resident, Dr. Peter Jannetta, has notably enhanced the neurosurgical approaches to treating complex nerve disorders.[25,27,37] Dr. Peter Jannetta discovered the trigeminal portio intermedia back in 1965 while conducting cranial nerve microdissections for dental students. He suggested that preserving these sensory fibers could prevent complete facial numbness. To treat TN, he and Rand came up with a subtemporal transtentorial method for selective rhizotomy.[24]

During his observations, Jannetta noticed the SCA pulsating and crushing the trigeminal nerve root, which he believed was the cause of the tic. He also proposed that treating vascular cross-compression could have therapeutic benefits. Jannetta explained his neurovascular compression (NVC) theory and suggested that decompressing the nerve in a non-traumatic way could potentially cure the disease without causing facial weakness.[27] In the first case, it was rare for the hemifacial spasm to be caused by a vein, but Jannetta's insight and skill helped to identify and fix the problem safely. The patient recovered well, and the spasms stopped the next day.[24]

A few months later, Jannetta and Rand performed the first MVD for TN, which was successful and provided permanent pain relief to the patient.[38] Over the next few decades, Jannetta continued to refine his NVC concept and the MVD procedure, which is now performed worldwide.

SUPERIOR LONG-TERM EFFICACY OF MVD COMPARED TO OTHER TREATMENTS

MVD is significantly more effective than other forms of treatment for TN in the long run. When performed by experienced surgeons, MVD not only swiftly alleviates pain but also exhibits relatively low rates of recurrence and complications. As the leading surgical option for treating TN, MVD is associated with better long-term success rates and reduced chances of recurrence despite offering only partial relief.[41] MVD is a unique and very successful therapeutic option for TN that provides long-term pain relief by reducing the compression of arteries and the thickened arachnoid on the trigeminal nerve. Singh *et al*. conducted a 5-year retrospective study involving 106 patients, demonstrating the efficacy of MVD. The findings suggest that in the hands of skilled practitioners, MVD remains a safe and economically viable choice for TN treatment, applicable to patients of all age groups.[43] Research studies have shown that MVD patients often report higher rates of satisfaction and significant improvements in quality of life compared to those undergoing peripheral nerve stimulation (PNS) or neuromodulation.[6,43] PNS typically involves the implantation of electrodes near the affected nerve, which are connected to an implanted pulse generator that delivers electrical impulses. These impulses can disrupt abnormal pain signals and provide relief to individuals suffering from TN.[6] Radiofrequency rhizotomy (RFN) presents a minimally invasive alternative, targeting specific pain-transmitting nerve fibers through radiofrequency radiation. Studies indicate notable enhancements in quality of life and patient-reported outcomes with RFN, with MVD patients expressing higher satisfaction rates.[26,29] SRS provides a non-invasive approach, delivering precise radiation beams to the trigeminal nerve root, thus alleviating pain without the necessity of surgery. Despite its appeal, MVD still exhibits significantly superior rates of complete pain relief and lower complications (17.6% vs. 19.3%) and recurrence rate (15.9% vs. 22.6%) in comparison to SRS.[5,42,46]

The method of managing MVD involves a surgical procedure designed to locate and relieve the pressure that the surrounding vascular structures are exerting on the trigeminal nerve. A tiny craniotomy allows the neurosurgeon to access the root entry zone (REZ) of the trigeminal nerve, where vascular compression frequently takes place. Using microsurgical techniques, the offending vessels are carefully dissected and padded with a Teflon felt or other suitable material to prevent further compression.[4]

The outcomes of MVD are remarkable, with many patients experiencing significant and sustained pain relief following the procedure. However, complications associated with MVD are also a point of concern and require careful consideration before opting for this treatment. The surgical procedure can be complex, requiring precision and expertise to navigate the delicate structures in the posterior fossa. Potential complications, although relatively low, include cerebrospinal fluid leakage, hearing loss, facial weakness, and infection. In addition, variability in outcomes poses a significant hurdle, with some patients experiencing suboptimal pain relief or recurrence of symptoms over time.[28,33]

HOW AWAKE SURGERY CHANGES THE LANDSCAPE OF MVD

The advent of awake surgery heralds numerous benefits, with the foremost being the optimization of tumor resection while preserving neurological function. Awake craniotomy offers a range of advantages, including a reduced necessity for postoperative monitoring in the Intensive Care Unit

(ICU), leading to shorter or even eliminated ICU stays.[8,21] Patients undergoing awake craniotomy also exhibit fewer neurological deficits (7% vs. 23%) and experience shorter hospital stays (1.7 vs. 9 days) compared to those undergoing craniotomy under general anesthesia.[18] Furthermore, patients undergoing awake craniotomy under sedation circumvent the need for general anesthesia, thereby avoiding the inherent risks associated with intubation and mechanical ventilation.[18]

In addition, postoperative discomfort, such as pain, nausea, and vomiting, is diminished in awake craniotomy compared to procedures conducted under general anesthesia.[30] Awake craniotomy offers precise motor and speech mapping, particularly beneficial when dealing with lesions in eloquent areas of the brain controlling motor or language functions. Language and motor mapping during awake craniotomy facilitate the identification and preservation of these critical areas, preventing inadvertent damage during resection. This method also allows for the exploration of fine, highly specialized movements, which may not be effectively monitored through peripheral motor-evoked potentials or asleep mapping.[22]

Moreover, comparative studies between awake and asleep surgeries demonstrate a higher quantity of total resections achievable through awake craniotomy, contributing to an increased extent of resection (EOR).[13] Enhanced EOR has been correlated with improved seizure control post-treatment, suggesting a potential predictive value for postoperative outcomes. Notably, the minimum threshold of EOR associated with seizure control aligns with values established for overall outcomes, indicating the possibility of using these thresholds to forecast postoperative seizure control effectively.[32] Thus, awake craniotomy not only enhances surgical precision but also contributes to improved patient outcomes, particularly in terms of neurological function preservation.[34]

In an investigation, Gubian and Rosahl's meta-analysis unveiled promising success rates for both MVD at 86.9% and radiosurgery at 71.1%.[19] These findings corroborate the well-established status of MVD as the primary treatment choice for TN, particularly among younger patients and those without concurrent health conditions. Historically, comorbidities have hindered the safety of MVD, excluding certain individuals from this effective treatment avenue and forcing them toward less optimal pain management methods.

The landscape of surgery undergoes a significant shift with the integration of awake procedures, as demonstrated by a recent study on TN. Abdulrauf *et al.* introduce a groundbreaking approach by demonstrating the feasibility of conducting awake MVD for TN. They suggest that within the framework of awake surgery, individuals who undergo MVD and experience persistent symptoms may benefit from additional insights gained during the awake phase.[2] By incorporating these insights into subsequent microsurgical interventions, there is potential for enhancing the success rate of the procedure. Encouragingly, all patients who experienced pain resolution intraoperatively remained free from pain postoperatively. However, one patient who did not achieve pain relief during surgery, despite multiple microsurgical attempts, continued to experience pain postoperatively.[2]

According to a study, it was observed that, except for Teflon granuloma, all other issues primarily arise due to the absence of intraoperative neurophysiological indicators that could promptly alert surgeons to suboptimal decompression during the surgery itself, thereby mitigating recurrences and the need for further interventions.[40] In response to these challenges, this study has endeavored to blend the benefits of awake anesthesia with minor refinements (such as utilizing a fat-Teflon sandwich instead of Teflon alone) to enhance the success rate of the gold standard technique, MVD. The preliminary experience with awake MVD underscores its safety, feasibility, and potential advantages for cranial nerve neuralgias. Notably, patients' responses during awake MVD serve as valuable guides for subsequent management, facilitating tailored approaches, and determining the necessity and extent of selective partial rhizotomy/internal neurolysis as adjuncts to MVD, thereby ensuring comprehensive pain relief, particularly in individuals lacking NVC or deemed unsuitable for general anesthesia.[40] Furthermore, it is believed that this approach can enhance the detection rate of NVC, particularly in magnetic resonance imaging (MRI)-negative cases harboring concealed offending vessels.[40]

FUTURE DIRECTIONS AND CHALLENGES OF AWAKE MVD FOR TN

The developments and challenges in awake craniotomy techniques may also apply to awake surgery for MVD in treating TN.[17] As surgical and anesthetic practices progress, future directions may involve identifying the safest and most tolerated anesthetic approach for awake MVD.[17]

New treatments such as targeted ultrasound provide fresh approaches to managing TN and have shown encouraging early outcomes in preclinical research. Targeted ultrasound relieves pain without requiring invasive surgery using precisely focused ultrasound waves to ablate the target tissue.[3] Despite their promise, more clinical studies are required to confirm their efficacy and safety in TN patients. A multidisciplinary strategy combining medication, interventional techniques, and surgical interventions is necessary to optimize patient outcomes and enhance the quality of life due to the subtleties and complexity of TN management. Moreover, adopting newer strategies to minimize sedatives and opioids could enhance patient comfort and safety during awake MVD procedures. Research could explore optimal airway devices and intravenous infusions tailored to individual patient responses using titration algorithms for improved outcomes.[16] The implementation of closed-loop control systems involves using real-time feedback to adjust mechanical ventilation parameters such as tidal volume and respiratory rate. This system tailors adjustments based on patient-specific variables and desired clinical targets. This advanced technology can enhance anesthesia management during awake MVD by ensuring precise control of variables critical for patient safety and comfort. A closed-loop control system predicts the respiratory mechanics of a patient and adjusts the ventilation settings accordingly using mathematical models.[16] Such devices allow anesthesiologists to maintain ideal end-tidal carbon dioxide levels during awake MVD treatments, reducing the danger of hyper- or hypocapnia and ensuring proper brain perfusion. Closed-loop control systems also provide the possibility of customized ventilation plans based on the physiological response and surgical needs of each patient. These systems ensure accurate control of variables like end-tidal carbon dioxide levels by continuously monitoring and adjusting ventilation parameters in real-time, reducing the difficulties associated with manual ventilation management, such as variability in patient response and the need for frequent adjustments during surgery.[31] These developments are intended to benefit awake MVD treatments for TN by optimizing surgical circumstances, improving patient safety, and improving results.[17]

Moreover, given the continuous progress in surgical methods and technology, it is clear that further investigation and refinement of endoscope-assisted procedures may be necessary in the future directions of MVD for TN. This means that there is a need to investigate further and refine the use of endoscopes alongside traditional operating microscopes in MVD procedures.[1] One major benefit of the combined method is that it integrates endoscopic and microscopic techniques to improve navigation and visualization in the surgical field. It blends the greater illumination and panoramic view of endoscopes with the accuracy of conventional operating microscopes. With this method, surgeons may better identify complex structures, thoroughly understand the surgical anatomy, and carry out precise procedures that yield better results. This is particularly important because such compression may not be fully appreciated with microscopic visualization alone.[9] By focusing on refining and expanding the application of endoscope-assisted techniques in awake MVD surgery for TN, the aim is to improve surgical precision and ultimately enhance patient outcomes.[7]

Challenges persist in MVD for TN as not all patients experience successful outcomes, with varied rates of pain relief and symptom recurrence. Factors influencing recurrence include pain location, gender, and vascular compression. However, other factors such as age, onset side, disease duration, and recurrence show partial relevance and lack statistical significance.[49] Addressing this requires larger studies and a comprehensive exploration of pathology and electrophysiology. Preoperative imaging techniques such as MRI and magnetic resonance angiography are vital for assessing neurovascular relationships, yet their accuracy may vary. Before surgery, a 3.0-Tesla MRI system was utilized alongside advanced three-dimensional MRI techniques, including magnetic resonance angiography and fast spoiled gradient recalled MRI, to evaluate the anatomical connection between neuronal and vascular structures at the trigeminal REZ (TREZ). The study revealed that in 27 out of 29 patients, or 93%, surgical findings and MRI results were consistent. Moreover, every patient who underwent MVD experienced complete pain relief. This underscores the utility of high-resolution MRI in identifying neurovascular contact at the TREZ.[14,20] Managing TN presents challenges due to arachnoid adhesions and abnormal anatomical relationships. Grasping these complexities is paramount for optimizing outcomes in MVD for TN.

CONCLUSION

The integration of awake surgery techniques, particularly awake MVD, represents a significant advancement in the treatment of TN. By optimizing surgical precision and patient safety, awake surgery techniques have the potential to enhance the success rates of MVD and improve patient outcomes. Despite these advancements, challenges remain in the field of MVD for TN. Variability in patient responses and the need for further refinement of surgical methods pose ongoing challenges. In addition, the identification of optimal anesthetic approaches for awake MVD and the integration of newer technologies, such as targeted ultrasound, require further investigation.

Future research should focus on refining awake surgery techniques and exploring new approaches to optimize outcomes in MVD for TN. Multidisciplinary collaboration and continued advancements in surgical methods and technology are essential for addressing the complexities of TN management and improving patient care.

Ethical approval

The Institutional Review Board approval is not required.

Declaration of patient consent

Patient's consent was not required as there are no patients in this study.

Financial support and sponsorship

Nil.

Conflicts of interest

There are no conflicts of interest.

Use of artificial intelligence (AI)-assisted technology for manuscript preparation

The authors confirm that there was no use of artificial intelligence (AI)-assisted technology for assisting in the writing or editing of the manuscript and no images were manipulated using AI.

REFERENCES

1. Abdeen K, Kato Y, Kiya N, Yoshida K, Kanno T. Neuroendoscopy in microvascular decompression for trigeminal neuralgia and hemifacial spasm: Technical note. Neurol Res 2000;22:522-6.
2. Abdulrauf SI, Urquiaga JF, Patel R, Albers JA, Sampat VB, Baumer M, *et al*. Awake Microvascular decompression for trigeminal neuralgia: Concept and initial results [published correction appears in World Neurosurg 2019;131:80]. World Neurosurg 2018;113:e309-13.
3. Allam AE, Khalil AA, Eltawab BA, Wu WT, Chang KV. Ultrasound-guided intervention for treatment of trigeminal neuralgia: An updated review of anatomy and techniques. Pain Res Manag 2018;2018:5480728.
4. Bendtsen L, Zakrzewska JM, Abbott J, Braschinsky M, Di Stefano G, Donnet A, *et al*. European Academy of neurology guideline on trigeminal neuralgia. Eur J Neurol 2019;26:831-49.
5. Berger I, Nayak N, Schuster J, Lee J, Stein S, Malhotra NR. Microvascular decompression versus stereotactic radiosurgery for trigeminal neuralgia: A decision analysis. Cureus 2017;9:e1000.
6. Bina RW, Palsma RS, Weinand ME, Kasoff WS. Peripheral nerve stimulation for refractory trigeminal pain: Recent single-institution case series with long-term follow-up and review of the literature. Neuromodulation 2020;23:796-804.
7. Bohman LE, Pierce J, Stephen JH, Sandhu S, Lee JY. Fully endoscopic microvascular decompression for trigeminal neuralgia: Technique review and early outcomes. Neurosurg Focus 2014;37:E18.
8. Brown T, Shah AH, Bregy A, Shah NH, Thambuswamy M, Barbarite E, *et al*. Awake craniotomy for brain tumor resection: The rule rather than the exception? J Neurosurg Anesthesiol 2013;25:240-7.
9. Charalampaki P, Kafadar AM, Grunert P, Ayyad A, Perneczky A. Vascular decompression of trigeminal and facial nerves in the posterior fossa under endoscope-assisted keyhole conditions. Skull Base 2008;18:117-28.
10. Cruccu G, Finnerup NB, Jensen TS, Scholz J, Sindou M, Svensson P, *et al*. Trigeminal neuralgia: New classification and diagnostic grading for practice and research. Neurology 2016;87:220-8.
11. Dandy WE: Concerning the case of trigeminal neuralgia. Am J Surg 1934;24:447-55.
12. De Toledo IP, Conti Réus J, Fernandes M, Porporatti AL, Peres MA, Takaschima A, *et al*. Prevalence of trigeminal neuralgia: A systematic review. J Am Dent Assoc 2016;147:570-6.e2.
13. Eseonu CI, Rincon-Torroella J, ReFaey K, Lee YM, Nangiana J, Vivas-Buitrago T, *et al*. Awake craniotomy vs craniotomy under general anesthesia for perirolandic Gliomas: Evaluating perioperative complications and extent of resection. Neurosurgery 2017;81:481-9.
14. Gamaleldin OA, Donia MM, Elsebaie NA, Abdelkhalek Abdelrazek A, Rayan T, Khalifa MH. Role of fused three-dimensional time-of-flight magnetic resonance angiography and 3-dimensional T2-weighted imaging sequences in neurovascular compression. World Neurosurg 2020;133:e180-6.
15. Gardner WJ, Miklos MV. Response of trigeminal neuralgia to "decompression" of sensory root; discussion of cause of trigeminal neuralgia. JAMA 1959;170:1773-6.
16. Gentilini A, Schaniel C, Morari M, Bieniok C, Wymann R, Schnider T. A new paradigm for the closed-loop intraoperative administration of analgesics in humans. IEEE Trans Biomed Eng 2002;49:289-99.
17. Ghazanwy M, Chakrabarti R, Tewari A, Sinha A. Awake craniotomy: A qualitative review and future challenges. Saudi J Anaesth 2014;8:529-39.
18. Groshev A, Padalia D, Patel S, Garcia-Getting R, Sahebjam S, Forsyth PA, *et al*. Clinical outcomes from maximum-safe resection of primary and metastatic brain tumors using awake craniotomy. Clin Neurol Neurosurg 2017;157:25-30.
19. Gubian A, Rosahl SK. Meta-analysis on safety and efficacy of microsurgical and radiosurgical treatment of trigeminal neuralgia. World Neurosurg 2017;103:757-67.
20. Hao YB, Zhang WJ, Chen MJ, Chai Y, Zhang WH, Wei WB. Sensitivity of magnetic resonance tomographic angiography for detecting the degree of neurovascular compression in trigeminal neuralgia. Neurol Sci 2020;41:2947-51.
21. Hervey-Jumper SL, Berger MS. Technical nuances of awake brain tumor surgery and the role of maximum safe resection. J Neurosurg Sci 2015;59:351-60.
22. Hervey-Jumper SL, Li J, Lau D, Molinaro AM, Perry DW, Meng L, *et al*. Awake craniotomy to maximize glioma resection: Methods and technical nuances over a 27-year period. J Neurosurg 2015;123:325-39.
23. Holste K, Chan AY, Rolston JD, Englot DJ. Pain outcomes following microvascular decompression for drug-resistant trigeminal neuralgia: A systematic review and meta-analysis. Neurosurgery 2020;86:182-90.
24. Jannetta PJ, Rand RW. Transtentorial retrogasserian rhizotomy in trigeminal neuralgia by microneurosurgical technique. Bull Los Angeles Neurol Soc 1966;31:93-9.
25. Jannetta PJ. Microsurgical exploration and decompression of the facial nerve in hemifacial spasm. In: Skinner DB, Ebert PA, editors. Current Topics in Surgical Research. Vol. 2. New York: Academic Press; 1970. p. 217-20.
26. 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;48:524-32; discussion 532-4.

27. Kaufmann AM, Price AV. A history of the Jannetta procedure. J Neurosurg 2019;132:639-46.
28. Lee HS, Cho KR, Park K, Jeon C. Management of cerebrospinal fluid leakage after microvascular decompression surgery: Clinical strategy. Life (Basel) 2023;13:1771.
29. Maarbjerg S, Gozalov A, Olesen J, Bendtsen L. Trigeminal neuralgia--a prospective systematic study of clinical characteristics in 158 patients. Headache 201454:1574-82.
30. Manninen PH, Tan TK. Postoperative nausea and vomiting after craniotomy for tumor surgery: A comparison between awake craniotomy and general anesthesia. J Clin Anesth 2002;14:279-83.
31. Martinoni EP, Pfister CA, Stadler KS, Schumacher PM, Leibundgut D, Bouillon T, *et al.* Model-based control of mechanical ventilation: Design and clinical validation. Br J Anaesth 2004;92:800-7.
32. Pallud J, Dezamis E. Functional and oncological outcomes following awake surgical resection using intraoperative cortico-subcortical functional mapping for supratentorial gliomas located in eloquent areas. Neurochirurgie 2017;63:208-18.
33. Park CK, Park BJ. Surgical treatment for trigeminal neuralgia. J Korean Neurosurg Soc 2022;65:615-21.
34. Patchana T, Lopez JA, Majeed G, Ho A, Alarcon T, Plantak N, *et al*. The awake craniotomy: A patient's experience and a literature review. Cureus 2022;14:e26441.
35. Peker S, Sirin A. Primary trigeminal neuralgia and the role of pars oralis of the spinal trigeminal nucleus. Med Hypotheses 2017;100:15-8.
36. Rana MH, Khan AA, Khalid I, Ishfaq M, Javali MA, Baig FA, *et al*. Therapeutic approach for trigeminal neuralgia: A systematic review. Biomedicines 2023;11:2606.
37. Rand RW, Kurze TL. Facial nerve preservation by posterior fossa transmeatal microdissection in total removal of acoustic tumors. J Neurol Neurosurg Psychiatry 1965;28:311-6.
38. Rand RW. Gardner neurovascular decompression of the trigeminal and facial nerves for tic douloureux and hemifacial spasm. Surg Neurol 1981;16:329-32.
39. Rand RW. The Gardner neurovascular decompression operation for trigeminal neuralgia. Acta neurochir 1981;58: 161-6.
40. Ratha V, Roopesh Kumar VR, Subramaniam S, Kumar S, Sankaran V, Suresh Bapu KR. Awake microvascular decompression with fat-Teflon sandwich technique: Clinical implications of a novel approach for cranial nerve neuralgias. J Clin Neurosci 2019;64:77-82.
41. Sade B, Lee JH. Microvascular decompression for trigeminal neuralgia. Neurosurg Clin N Am 2014;25:743-9.
42. Sandell T, Eide PK. Effect of microvascular decompression in trigeminal neuralgia patients with or without constant pain. Neurosurgery 2008;63:93-9; discussion 99-100.
43. Singh D, Dutta G, Jagetia A, Singh H, Srivastava AK, Tandon M, *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:S206-12.
44. Spina A, Mortini P, Alemanno F, Houdayer E, Iannaccone S. Trigeminal neuralgia: Toward a multimodal approach. World Neurosurg 2017;103:220-30.
45. Taarnhøj P. Decompression of the trigeminal root. J Neurosurg 1954;11:299-305.
46. Wang DD, Raygor KP, Cage TA, Ward MM, Westcott S, Barbaro NM, *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.
47. Xia L, Zhong J, Zhu J, Wang YN, Dou NN, Liu MX, *et al*. Effectiveness and safety of microvascular decompression surgery for treatment of trigeminal neuralgia: A systematic review. J Craniofac Surg 2014;25:1413-7.
48. Zakrzewska JM, Linskey ME. Trigeminal neuralgia. BMJ 2014;348:g474.
49. Zheng JH, Sun K, Zhang HT, Xie YJ, Wang-Yang LX, Chen HY, *et al*. A study on the recurrence rate of trigeminal neuralgia after MVD and the related factors. J Neurol Surg B Skull Base 2020;81:572-8.

How to cite this article: Fareed A, Iftikhar Z, Haider R, Shah SI, Ennabe M, Alan A, *et al*. Awake neurosurgery: Advancements in microvascular decompression for trigeminal neuralgia. Surg Neurol Int. 2024;15:215. doi: 10.25259/SNI_286_2024