Brain and Spine 4 (2024) 102798

Contents lists available at ScienceDirect

Brain and Spine

journal homepage: www.journals.elsevier.com/brain-and-spine

Frame navigation guided percutaneous balloon compression for intractable trigeminal neuralgia secondary to multiple sclerosis

Jose E. Valerio Pascua [a,b,c], Penelope Mantilla Farfan [b], Maria Paula Fernandez [b], Noe Santiago Rea [b], Matteo Borro [b], Andres M. Alvarez-Pinzon [c,d,e,*]

[a] Neurosurgery Oncology, Neurosurgery Oncology Center of Excellence at Miami Neuroscience Center, Larkin Healthcare System, Miami, FL, USA
[b] Neurological Surgery, Palmetto General Hospital at Steward Family Hospital, Hialeah, FL, USA
[c] Neurological Surgery, Latinoamerica Valerio Foundation, Weston, FL, USA
[d] Stanford Graduate School of Business, 655 Knight Way, Stanford, CA, 94305, USA
[e] Institute of Neuroscience of Castilla and Leon (INCYL), University of Salamanca (USAL), Salamanca, Spain

A R T I C L E I N F O

Handling editor: W Peul

Keywords:
Multiple sclerosis
Balloon compression
Intractable trigeminal neuralgia
Demyelination
Minimally invasive

A B S T R A C T

Background: Patients with multiple sclerosis (MS) are more likely to develop trigeminal neuralgia (TN) compared to the regular population, due to scarring of the nerve and development of a demyelination plaque. Despite treatment, approximately 10% of MS patients treated for TN experience symptom recurrence, including the development of MS-like symptoms such as optic neuritis and bilateral facial pain.
Methods: A computed tomography (CT) scan was performed preoperatively on two patients diagnosed with multiple sclerosis (MS) who experienced secondary trigeminal neuralgia (TN). A precise reference frame was strapped firmly to the patient's forehead during the intraoperative procedure. Preliminary CT images were registered using the navigation system and the bony landmarks were set.
Case description: Two patients diagnosed with multiple sclerosis (MS) who experienced refractory trigeminal neuralgia (TN) underwent percutaneous balloon compression. Initial conservative treatment and one dosage of Gamma Knife Radiosurgery (GKR) resulted in symptom control for a few weeks. Both patients had an acute recurrence of pain; thus, percutaneous retrogasserian balloon compression was performed. During follow-up, the patients reported a 70% decrease in pain after the procedure, with minimal recurrence of shooting episodes.
Conclusion: Management of trigeminal neuralgia secondary to drug-resistant multiple sclerosis presents a persistent challenge. The percutaneous technique for retrogasserian balloon compression may offer a solution for some patients, but it presents unique challenges for neurosurgeons. Given the complexity of the pathogenesis, target identification, and the potential absence of neurovascular conflict, microvascular decompression remains a debated approach for this patient population. While stereotactic radiosurgery may be a promising alternative.

1. Introduction

Multiple Sclerosis (MS) is a complex demyelinating disorder of the central nervous system that affects an estimated 2.8 million people worldwide (Walton et al., 2020). MS is characterized as a debilitating disease that is often associated with neuropathic pain. The onset of MS is often in young adulthood, between 20 and 40 years of age, with women being two to three times more likely to experience this disorder (Headache Classification Committee of the, 2018). A study showed that prevalence in 2020 was 35.9 per 100,000 people (Amato et al., 2018).

In addition to neuropathic pain, other incapacitating symptoms of MS include tonic spasms, Lhermitte's sign, headache, and trigeminal neuralgia (Racke et al., 2021).

MS-related Trigeminal Neuralgia (TN) is considered a complex syndrome characterized by intermittent sharp shooting pain along the distribution of the trigeminal nerve. This type of pain occurs more frequently (about 80% of patients) in the V2 and V3 branches of the trigeminal nerve (Headache Classification Committee of the, 2018). The etiology of these symptoms is thought to be caused by demyelination of the intra-axial and extra-axial primary afferent trigeminal nerves, which

* Corresponding author. Neurosurgery oncology, Neurosurgery Oncology Center of Excellence at Miami Neuroscience Center, Larkin Healthcare System, Miami, FL, USA.
E-mail addresses: borromatteo@libero.it (M. Borro), andresmauricioalvarez07@gmail.com (A.M. Alvarez-Pinzon).

https://doi.org/10.1016/j.bas.2024.102798
Received 5 September 2023; Received in revised form 25 March 2024; Accepted 30 March 2024
Available online 1 April 2024

disrupt normal nerve signals and lead to pain. This type of pain is postulated to be an electric machine with paroxysmal high frequency. Demyelination disrupts normal nerve signals and causes pain. Patients report initially a tingling, or "pins and needles" sensation followed by an electric shock (Headache Classification Committee of the, 2018). These symptoms are similar to those reported in idiopathic trigeminal neuralgia, with the presence of trigger points, and in some cases with the phenomenon of L'hermitte; described as a short, electric shock discharge, usually caused by certain exacerbating factors such as bending of the neck. Although paroxysmal pain is the hallmark of trigeminal neuralgia, some patients can complain of constant long-lasting pain between each attack, described as burning, throbbing, or aching pain (Cruccu et al., 2020). Even, TN can occur as a progressive condition that becomes increasingly debilitating with short periods of remission between attacks (Headache Classification Committee of the, 2018).

The treatment of MS-associated trigeminal neuralgia is complex given that symptoms can present in the acute or chronic setting, in addition to the morphologic changes that occur in the trigeminal nerve. Therefore, an interdisciplinary approach is necessary to find the most suitable plan with minimal side effects. Neurosurgery assessments are frequently encountered with treatment options that include Gamma knife radiosurgery, percutaneous procedures, and microsurgical decompression. A review of the literature reports many treatment failures in MS patients; however, balloon compression may be a possible tool to use in the acute setting to treat an intractable pain episode of TN (Bick and Eskandar, 2017). Thus, in the present paper, we illustrate two cases of patients with secondary trigeminal neuralgia who underwent percutaneous balloon compression as a minimally invasive procedure for symptom control.

2. Methods

In the selected two cases, we performed a Percutaneous Balloon Compression of the Gasser Ganglia due to the ineffective response to medical therapy and stereotactic radiosurgery. A preoperative Computed Tomography (CT) scan was conducted, and the images were introduced into a navigation system. Intraoperatively, a precise reference frame was strapped firmly to the patient's forehead. This system was used to precisely align the patient's bony landmarks during the procedure. A reference frame was firmly attached to the patient's forehead and the procedure was performed under general anesthesia with intratracheal intubation.

The procedure was carried out using a No. 4 Fogarty catheter, filled with radiographic contrast to ensure patency. The catheter was inserted into the needle, guided by fluoroscopy, and positioned at the tip of the needle. The patient was placed in the neutral supine position and a portable imaging unit was used to obtain a lateral view of the skull (see Fig. 1).

The percutaneous puncture needle was directed to the foramen ovale, with the entry point on the cheek located 2.5 cm lateral to the labial commissure. The balloon was then inflated with 1.0–3.0 ml of radio-opaque contrast, and the shape and position of the balloon were checked relative to neighboring bone landmarks (see Fig. 2). If the position was incorrect, the balloon was immediately deflated and the catheter was repositioned. The compression was maintained for a duration of 120 s.

After compression, the balloon catheter and cannula were removed, and the cheek was compressed for a few minutes. The patients were usually discharged the day following the procedure.

The entire procedure was performed with the utmost care and precision to ensure a successful outcome. The procedure's goal was to provide pain relief for patients suffering from trigeminal neuralgia and its success was evaluated based on the patients' response to treatment. The procedure was carried out in a controlled and safe manner, with the use of advanced medical technology and techniques.

Fig. 1. Intraoperative fluoroscopy used in Percutaneous Balloon Compression. The figure is showing the use of intraoperative fluoroscopy during percutaneous balloon compression (PBC) surgery. Two C-arm fluoroscopes are positioned in the operating room in an antero-posterior (A/P) and lateral plane. The needle is introduced 2.5 cm lateral to the oral commissure and directed towards the foramen ovale under fluoroscopic guidance to avoid any damage to nearby neurovascular structures. The figure demonstrates the use of fluoroscopy to guide the placement of the needle and ensure accuracy during the PBC procedure.

3. Case presentation

3.1. Case 1

A 38-year-old female patient reported a four-year history of shooting pain in the right side of her face, affecting her eyes, jaw, teeth, and tongue. Despite being treated with carbamazepine 600 mg daily, her symptoms showed minimal improvement. The patient underwent three dental procedures, but the pain persisted. A session of Gamma Knife radiosurgery was performed and provided good control of the pain for one year. However, the patient experienced a sub-acute episode of intense right-sided shooting facial pain, rated 10/10 on the Visual Analogue Scale (VAS). Despite seeking treatment at the ER and receiving intravenous opioids and neuromodulators, she did not experience pain relief.

As a last resort, the patient underwent a percutaneous balloon compression (PBC) procedure, which provided immediate and prolonged pain relief within three months, reducing her pain level to 5/10 on the VAS. Pregabalin gradually tapered off and the patient was discharged with a reduced dose of carbamazepine (600 mg daily). Unfortunately, after 16 months, symptoms began to recur in the V1 and V2 distributions, leading to another PBC procedure that resulted in a good outcome and a further reduction in carbamazepine dose (400 mg daily).

3.2. Case 2

A 56-year-old woman presented with a ten-year history of left-sided facial pain, localized to her eye and nose. Initially, she was treated with pregabalin 300 mg daily and amitriptyline 25 mg daily which provided pain control for two years. However, the patient's pain worsened and became debilitating, affecting the V1 – V2 dermatome. She underwent Gamma Knife radiosurgery which improved her symptoms for one month. However, 15 months later, she was diagnosed with secondary progressive multiple sclerosis, and her symptoms worsened to affect all three dermatomes. Despite being prescribed carbamazepine and pregabalin, adverse events were noted leading to treatment failure. The patient underwent percutaneous balloon compression three times with

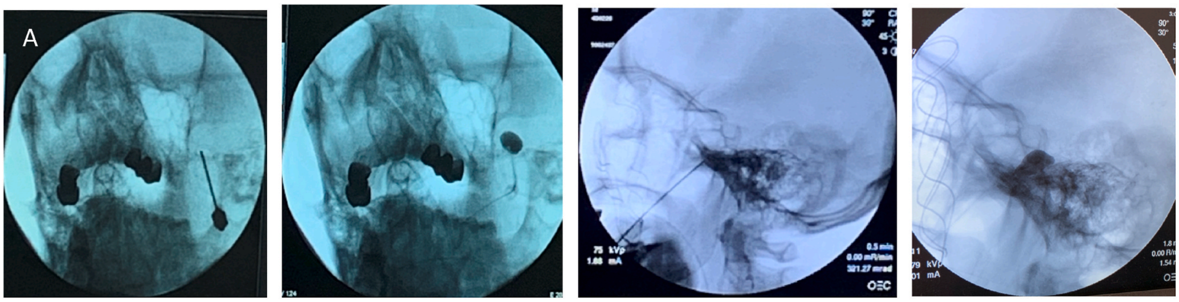

Fig. 2. Intraoperative fluoroscopic images in Percutaneous Balloon Compression.
This figure illustrates the use of intraoperative fluoroscopy during a percutaneous balloon compression procedure. Picture **A** shows the needle inside the foramen ovale, guided by fluoroscopy and the navigation system based on a preoperative CT scan. The needle is inserted 2 cm lateral to the oral commissure and is directed towards the foramen ovale, guided by fluoroscopic images. Picture **B** displays the balloon being insufflated at the tip of the catheter located in the foramen ovale. (A and B – Antero/Posterior Fluoroscopy). Picture **C** shows the needle directed towards the foramen ovale as seen on lateral fluoroscopy. Finally, picture **D** shows the balloon being insufflated with 1 cc of radio-opaque contrast on lateral fluoroscopy. These images demonstrate the use of imaging technology to guide the procedure and ensure the precise and safe placement of the balloon.

inflation lasting 1 min each (Based on the recurrence of symptoms). The procedure led to a 60% improvement in pain management immediately after the surgery. However, three weeks later, the patient developed continuous left-sided facial pain along the V1 distribution. Medical therapy with pregabalin 150 mg daily was resumed, resulting in improvement in pain control within eight weeks.

4. Discussion

TN is a condition characterized by intense, unilateral shock-like facial pain. The etiology of TN can be classified into two categories: idiopathic or essential TN, where the cause is unknown, Patients describe a temporary, intermittent, and intense unilateral shock-like pain that affects one or more divisions of the trigeminal nerve, and symptomatic or secondary TN, where the cause is known, most commonly due to posterior fossa tumors or multiple sclerosis. (Gambeta et al., 2020). According to Burchiel's classification of facial pain syndromes, a proposed system includes seven categories based on the history and quality of patient pain (Eller et al., 2005). The classification of facial pain syndromes includes trigeminal neuropathic pain, which is caused by unintentional injury to the trigeminal nerve or surgery; trigeminal deafferentation pain, which results from deliberate nerve injury, peripheral nerve ablation, gangliolysis, or rhizotomy to treat TN or other facial pain; post-herpetic neuralgia, which occurs after a herpes zoster outbreak in the cutaneous distribution of the trigeminal nerve; and TN and symptomatic outcomes in multiple sclerosis. Atypical facial pain is synonymous with high somatoform pain disorder.

TN, in general, is usually caused by demyelination of the trigeminal sensory fibers either within the nerve root or, less frequently, in the brainstem, and has been associated with neurovascular conflict in some cases (Chen et al., 2022). MS demyelination plate covers the inlet region of the trigeminal nerve root in the projection. Despite this, several studies have described the association of neurovascular conflict in some of the patients (Paulo et al., 2020; Hatipoglu et al., 2021). Demyelination commonly occurs along the proximal portion of the trigeminal nerve root and sometimes extends to its junction with the peripheral nerve. Studies have shown additional findings, including focal arachnoiditis at the nerve entry site or gliosis (Mizobuchi et al., 2021). Regions of demyelination typically exhibit a greater number of astrocyte processes that are widely distributed and the presence of lipid-laden macrophages. There may also be a variable number of myelinated fibers juxtaposed with axons within and adjacent to thin demyelination regions (Lassmann, 2018).

Percutaneous techniques for treating TN include radiofrequency rhizotomy (RFR), percutaneous balloon compression (PBC), and percutaneous retro-gasserian glycerol rhizotomy (PRGR). RFR has been reported to be as effective as microvascular decompression (MVD) for pain control (Kao et al., 2022), a recent meta-analysis reported that MVD was associated with a lower number of patients with pain than PBC (Nascimento et al., 2023). but MVD is an invasive procedure with a higher incidence of serious complications, such as hearing loss, tinnitus, facial weakness, aseptic meningitis, Hydrocephalus, Cerebrospinal Fluid Leak, Cerebellar infarct or hematoma, Anesthesia Dolorosa (Bick and Eskandar, 2017). Table 1 summarizes intra- and postoperative complications (Bick and Eskandar, 2017; Ying et al., 2017; Feng et al., 2023; Chang et al., 2022). Peripheral Nerve Block (PBC) provides a prolonged period of pain relief and has a lower incidence of complications compared to Radiofrequency Rhizotomy (RFR).

The shape of the balloon used in PBC can impact the clinical outcomes, with pears-shaped balloons being associated with superior pain relief compared to other shapes (Sun et al., 2021). In patients with MS

Table 1
PBC short- and medium-term complications.

Intraoperative complications[a]	Post-operative complications	
- Blood pressure rise	- Hypesthesia	- Persistent numbness
- Tachycardia	- Decreased/loss of corneal reflex	- Trigeminal nerve Dysfunction
- Bradycardia	- Masseter weakness	- Hearing loss
- Sudden hypotension	- Cheek hematoma	- Ipsilateral facial
	- Aseptic meningitis	- Anesthesia dolorosa
	- Bacterial meningitis	- Dysesthesia
	- Pseudoaneurysm	- Hyperesthesia
	- Higher rate of trigeminal reflex bradycardia and hypotension	- Viral herpes
	- Elevated odor threshold	- Cranial nerve(s) III, IV, and/or VI palsy
	- Keratitis	- Diplopia
	- Headache	- Arterial hemorrhage

[a] Trigeminocardiac reflex (TCR) is a brainstem reflex that manifests as sudden onset of hemodynamic perturbation in blood pressure (MABP) and heart rate (HR), as apnea and as gastric hypermotility during stimulation of any branches of the trigeminal nerve. The TCR is a clinical phenomenon characterized by the sudden initiation of hemodynamic disruptions (acute changes in mean arterial pressure, decreased heart rate, and asystole), respiratory alterations (apnea), and gastric alterations (hypermotility) in response to stimulation of any branch along the course of the fifth cranial nerve. This stimulation causes the nerve to transmit neuronal signals to the sensory nucleus of the trigeminal nerve via the Gasserian ganglion. The signals are interconnected within the sensory nucleus via an established polysynaptic and excitatory link to the reticular formation. Antagonists of 5-HT1A and 5-HT2A receptors appear to differentially enhance and depress this connection endogenously.

who have been treated with Gamma Knife radiosurgery, TN treatment with balloon compression can be performed, but the foramen ovale may be more difficult to identify due to radiation-induced adhesions. CT-guided percutaneous rhizotomy or neuro-navigation systems may facilitate needle placement and reduce the risk of complications in such cases (Pérez-Bovet et al., 2022). Having an adequate anatomical localization is crucial during the procedure, as the puncture of unwanted neuro-vascular structures can result in various complications such as cranial nerve palsy, cerebrospinal fluid leak, bradycardia, carotid-cavernous fistula, intracranial hemorrhage, and others (Xia et al., 2022)Meuwly et al., 2015. The knowledge of the neuroanatomy and relationship of the foramen ovale is mandatory in avoiding these complications. Thus, the correction of angular distances, the proper direction of the needle, and the appropriate identification of the foramen ovale can enhance the safety of this procedure.

Stereotactic radiosurgery (SRS) is another alternative treatment that can effectively treat TN in MS. SRS is less invasive and accurate than open surgery and percutaneous techniques but has a higher recurrence rate and a longer latency period to provide pain relief after radiation treatment compared to open surgery and percutaneous techniques. The disadvantages of radiosurgery include a high rate of recurrence and a delayed onset of pain relief after radiation treatment, as evidenced in the current cases (Tuleasca et al., 2018). In the two cases described, both patients provided an adequate response to SRS, but relapse in symptoms was seen in both cases. SRS can be used in patients with MS with a recurrence of intractable pain, but long-term pain control cannot be guaranteed (Franzini et al., 2021).

5. Conclusions

The conclusion of this study highlights the difficulty in managing the pain caused by multiple sclerosis. The use of percutaneous techniques to treat refractory TN has seen an increase in popularity, with positive outcomes reported in small patient groups. Retrograde balloon compression is a minimally invasive approach that provides pain relief in sub-acute TN cases. However, it is crucial to maintain proper anatomical localization during the procedure to minimize the risk of complications. The role of microvascular decompression in treating TN in this patient population remains a matter of debate, given the complexity of the pathogenesis, the target, and, in some cases, the absence of neurovascular conflict. Further research is required to determine the generalizability of the findings from this case series to the larger population.

Human subjects

Consent was obtained or waived by all participants in this study. Larkin Healthcare System issued approval LCH-8-062021.

Conflicts of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Author contributions

Each author made substantial contributions to the conception, design, execution, and analysis of this research, as well as to the preparation and critical revision of the manuscript. Dr. Jose Valerio Pascua and Dr. Andres Alvarez-Pinzon served dual roles as both senior and first authors of the study and the accompanying case series. The contributions of all authors satisfy the following criteria: 1. Substantial contributions to the conception or design of the work; or the acquisition, analysis, or interpretation of data for the work. 2. Drafting the work or revising it critically for important intellectual content. 3. Final approval of the version to be published. 4. Agreement to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

Funding

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Authorship statement

Each author made substantial contributions to the conception, design, execution, and analysis of this research, as well as to the preparation and critical revision of the manuscript. Dr. Jose Valerio Pascua and Dr. Andres Alvarez-Pinzon served dual roles as both senior and first authors of the study and the accompanying case series. The contributions of all authors satisfy the following criteria: 1. Substantial contributions to the conception or design of the work; or the acquisition, analysis, or interpretation of data for the work. 2. Drafting the work or revising it critically for important intellectual content. 3. Final approval of the version to be published. 4. Agreement to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

We gratefully acknowledge the invaluable support of the Latino America Valerio Foundation in our research endeavors. Their commitment to the pursuit of knowledge has played a pivotal role. We are pleased to share that this paper has been selected for presentation at the EANS Neurosurgery Oncology section in Barcelona, Spain, 2023.

References

Amato, M.P., Derfuss, T., Hemmer, B., et al., 2018. Environmental modifiable risk factors for multiple sclerosis: report from the 2016 ECTRIMS focused workshop. Mult. Scler. 24 (5), 590–603. https://doi.org/10.1177/1352458516686847.

Bick, S.K.B., Eskandar, E.N., 2017. Surgical treatment of trigeminal neuralgia. Neurosurg. Clin. 28 (3), 429–438. https://doi.org/10.1016/j.nec.2017.02.009.

Chang, K.W., Jung, H.H., Chang, J.W., 2022. Percutaneous procedures for trigeminal neuralgia. J Korean Neurosurg Soc 65 (5), 622–632. https://doi.org/10.3340/jkns.2022.0074.

Chen, Q., Yi, D.I., Perez, J.N.J., et al., 2022. The molecular basis and pathophysiology of trigeminal neuralgia. Int. J. Mol. Sci. 23 (7) https://doi.org/10.3390/ijms23073604.

Cruccu, G., Di Stefano, G., Truini, A., 2020. Trigeminal neuralgia. N. Engl. J. Med. 383 (8), 754–762. https://doi.org/10.1056/NEJMra1914484.

Eller, J.L., Raslan, A.M., Burchiel, K.J., 2005. Trigeminal neuralgia: definition and classification. Neurosurg. Focus 18 (5), E3. https://doi.org/10.3171/foc.2005.18.5.4.

Feng, D., Zhang, Y., Li, D., et al., 2023. Percutaneous ballon compression for recurrent TN —a retrospective study of 33 cases. Front. Neurol. 14 https://doi.org/10.3389/fneur.2023.1292804.

Franzini, A., Tropeano, M.P., Olei, S., et al., 2021. Gamma knife radiosurgery for the treatment of trigeminal neuralgia in patients with multiple sclerosis: a single-center retrospective study and literature review. World Neurosurg 149, e92–e100. https://doi.org/10.1016/j.wneu.2021.02.074.

Gambeta, E., Chichorro, J.G., Zamponi, G.W., 2020. Trigeminal neuralgia: an overview from pathophysiology to pharmacological treatments. Mol. Pain 16, 1744806920901890. https://doi.org/10.1177/1744806920901890.

Hatipoglu, Majernik G., Al-Afif, S., Heissler, H.E., Krauss, J.K., 2021. Operative findings and outcome of microvascular decompression/adhesiolysis for trigeminal neuralgia in multiple sclerosis without demyelinating brain stem lesions. Clin. Neurol. Neurosurg. 200, 106376 https://doi.org/10.1016/j.clineuro.2020.106376.

Headache Classification Committee of the International Headache Society (IHS) The International Classification of Headache Disorders, 3rd edition. Cephalalgia. 2018; 38(1):1-211. doi:10.1177/0333102417738202.

Kao, C.H., Lee, M.H., Yang, J.T., Tsai, Y.H., Lin, M.H.C., 2022. Percutaneous radiofrequency rhizotomy is equally effective for trigeminal neuralgia patients with or without neurovascular compression. Pain Med. 23 (4), 807–814. https://doi.org/10.1093/pm/pnab221.

Lassmann, H., 2018. Multiple sclerosis pathology. Cold Spring Harb Perspect Med. 8 (3) https://doi.org/10.1101/cshperspect.a028936.

Meuwly, C, Golanov, E, Chowdhury, T, Erne, P, Schaller, B, 2015. Trigeminal cardiac reflex: new thinking model about the definition based on a literature review. Medicine (Baltimore) 94 (5), e484. https://doi.org/10.1097/MD.0000000000000484.

Mizobuchi, Y., Nagahiro, S., Kondo, A., et al., 2021. Microvascular decompression for trigeminal neuralgia: a prospective, multicenter study. Neurosurgery 89 (4), 557–564. https://doi.org/10.1093/neuros/nyab229.

Nascimento, R.F.V., Pipek, L.Z., de Aguiar, P.H.P., 2023. Is percutaneous balloon compression better than microvascular decompression to treat trigeminal neuralgia? A systematic review and meta-analysis. J. Clin. Neurosci. 109, 11–20. https://doi.org/10.1016/j.jocn.2023.01.002.

Paulo, D.L., Lopez, A.M., Jermakowicz, W.J., et al., 2020. Microvascular decompression for trigeminal neuralgia in patients with multiple sclerosis: predictors of treatment success. World Neurosurg 136, e165–e170. https://doi.org/10.1016/j.wneu.2019.12.081.

Pérez-Bovet, J., Caro Cardera, J.L., Rimbau Muñoz, J., 2022. Frameless navigation-guided percutaneous rhizotomy of the trigeminal nerve: an appraisal of the literature. Neurosurg. Rev. 45 (1), 405–410. https://doi.org/10.1007/s10143-021-01575-5.

Racke, M.K., Frohman, E.M., Frohman, T., 2021. Pain in multiple sclerosis: understanding pathophysiology, diagnosis, and management through clinical vignettes. Front. Neurol. 12, 799698 https://doi.org/10.3389/fneur.2021.799698.

Sun, C., Zheng, W., Zhu, Q., Du, Q., Yu, W., 2021. The transformation of the balloon shape in percutaneous balloon compression for trigeminal neuralgia. J. Pain Res. 14, 3805–3814. https://doi.org/10.2147/JPR.S343783.

Tuleasca, C., Régis, J., Sahgal, A., et al., 2018. Stereotactic radiosurgery for trigeminal neuralgia: a systematic review. J. Neurosurg. 130 (3), 733–757. https://doi.org/10.3171/2017.9.JNS17545.

Walton, C., King, R., Rechtman, L., et al., 2020. Rising prevalence of multiple sclerosis worldwide: insights from the Atlas of MS, third edition. Multiple Sclerosis Journal 26 (14), 1816–1821. https://doi.org/10.1177/1352458520970841.

Xia, Y., Yu, G., Min, F., Xiang, H., Huang, J., Leng, J., 2022. The focus and new progress of percutaneous balloon compression for the treatment of trigeminal neuralgia. J. Pain Res. 15, 3059–3068. https://doi.org/10.2147/JPR.S374433.

Ying, X., Wang, H., Deng, S., Chen, Y., Zhang, J., Yu, W., 2017. Long-term outcome of percutaneous balloon compression for trigeminal neuralgia patients elder than 80 years. Medicine 96 (39), e8199. https://doi.org/10.1097/MD.0000000000008199.