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Review Article

Chinese Expert Consensus on Percutaneous Balloon Compression for Trigeminal Neuralgia (2022)

Ren Yu'e[1], Liu Xiaohui[1], Cheng Zhixiang[2], Fan Xiaochong[3], Fan Bifa[4], Huang Dong[5], Hu Yongsheng[6], Jiang Zongbin[7], Luo Fang[8], Ma Ke[9], Qian Tao[10], Sun Tao[11], Sun Hongtao[12], Yang Liqiang[13], Yu Wenhua[14], Zhong Jun[15], Zhao Zongmao[16], Zhou Huacheng[17], Liu Guangzhao[1, *]

[1]Department of Painology, The Second Hospital of Hebei Medical University, Shijiazhuang, China

[2]Department of Painology, The Second Affiliated Hospital of Nanjing Medical University, Nanjing, China

[3]Department of Pain Medicine, The First Affiliated Hospital of Zhengzhou University, Zhengzhou, China

[4]Department of Pain Medicine, China-Japan Friendship Hospital, Beijing, China

[5]Department of Pain Medicine, The Third Xiangya Hospital of Central South University, Changsha, China

[6]Department of Functional Neurosurgery, Xuanwu Hospital Capital Medical University, Beijing, China

[7]Department of Pain Medicine, The Second Affiliated Hospital of Guangxi Medical University, Nanning, China

[8]Department of Pain Medicine, Beijing Tiantan Hospital, Beijing, China

[9]Department of Pain Medicine, Xinhua Hospital Affiliated to Shanghai Jiao Tong University School of Medicine, Shanghai, China

[10]Department of Neurosurgery, Hebei General Hospital, Shijiazhuang, China

[11]Department of Pain Medicine, Provincial Hospital Affiliated to Shandong First Medical University, Jinan, China

[12]Department of Neurosurgery, Chinese People's Armed Police Force Characteristic Medical Center, Tianjin, China

[13]Department of Pain Medicine, Xuanwu Hospital Capital Medical University, Beijing, China

[14]Department of Neurosurgery, First People's Hospital of Hangzhou, Hangzhou, China

[15]Department of Neurosurgery, Xinhua Hospital Affiliated to Shanghai Jiao Tong University School of Medicine, Shanghai, China

[16]Department of Neurosurgery, The Second Hospital of Hebei Medical University, Shijiazhuang, China

[17]Department of Pain Medicine, The Fourth Affiliated Hospital of Harbin Medical University, Harbin, China

Abstract

Percutaneous balloon compression (PBC) is recognized as a simple, safe, and effective intervention for trigeminal neuralgia (TN) and has been widely adopted in clinical practice across China. However, variations in its application exist among different regions. To standardize procedural protocols and enhance clinical outcomes, a multidisciplinary panel of Chinese experts from pain medicine and neurosurgery collaboratively developed this clinical expert consensus. The consensus formulation involved a systematic literature review of major databases, including Wanfang and PubMed, among others, and

*Corresponding author: liuguangzhao100@sina.com (Liu Guangzhao)

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focusing on high-quality evidence such as systematic reviews, meta-analyses, randomized controlled trials, expert consensus statements, and clinical guidelines. Using the Grading of Recommendations, Assessment, Development, and Evaluation (GRADE) framework and structured consensus conference methods, the panel held iterative discussions and conducted voting sessions to finalize the recommendations. This document summarizes key aspects of PBC, including relevant anatomy, mechanisms of action, indications, contraindications, detailed operative techniques, and efficacy evaluation. It aims to serve as a practical reference for clinicians to standardize and optimize the use of PBC in the treatment of trigeminal neuralgia.

Keywords

Percutaneous Balloon Compression, Trigeminal Neuralgia, Pain, Expert Consensus

1. Introduction

Trigeminal neuralgia (TN) is a condition marked by unilateral, paroxysmal, and lancinating pain in the distribution of the trigeminal nerve [1]. Since its introduction by Mullan and colleagues in 1983 [2], percutaneous balloon compression (PBC) has been increasingly adopted in China owing to its procedural simplicity, safety, and clinical efficacy, with some considering it a first-line surgical intervention. To address variations in practice across regions and specialties, a panel of Chinese experts has developed this consensus document, outlining indications, contraindications, technical procedures, and outcome measures for PBC in TN, with the aim of standardizing its clinical use.

About the Anatomy

The trigeminal nerve (CN V: cranial nerves V) is a mixed nerve, primarily composed of general somatic afferent (sensory) fibers, with a minor special visceral efferent (motor) component. The cell bodies of its sensory fibers reside in the trigeminal ganglion. Their peripheral processes form three divisions—the ophthalmic (V1), maxillary (V2), and mandibular (V3) nerves—which exit the skull via the superior orbital fissure, foramen rotundum, and foramen ovale, respectively. The central processes form the sensory root, entering the pons to synapse in specific brainstem nuclei: the spinal trigeminal nucleus (pain and temperature), the pontine nucleus (touch), and the mesencephalic nucleus (proprioception) [3]. (Figure 1).

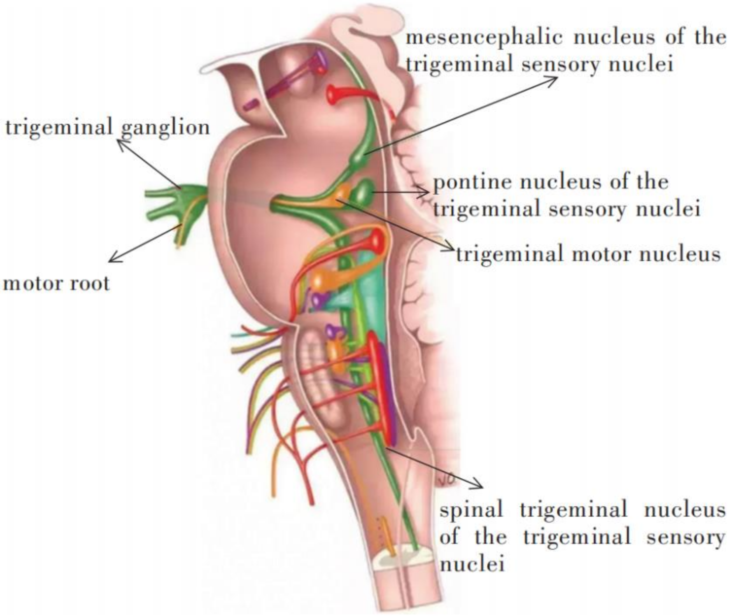

Figure 1. *Schematic diagram of the trigeminal nucleus.*

Note: The trigeminal sensory nuclei consist of the mesencephalic nucleus (proprioception), the pontine/principal nucleus (tactile sensation), and the spinal trigeminal nucleus (pain and temperature), all processing ipsilateral inputs. The trigeminal motor nucleus, located anteromedial to the pontine nucleus in the pons and also termed the "masticatory nucleus," controls masticatory muscle movement.

The motor fibers of the trigeminal nerve arise from the trigeminal motor nucleus in the mid-pons. Their axons form the motor root, which exits the brainstem at the pontine base-crus junction. The sensory root courses alongside the motor root, passing inferomedially to it through the trigeminal foramen into Meckel's cave in the middle cranial fossa. There, it expands into the trigeminal ganglion, giving rise to the ophthalmic, maxillary, and mandibular nerves, all of which exit the cranial cavity. Within Meckel's cave, the motor root lies inferior to the trigeminal ganglion without entering it. After passing beneath the ganglion, it exits the skull through the foramen ovale and joins the mandibular nerve (Figure 2) [3], innervating the masticatory muscles of the face (masseter, temporalis, and medial and lateral pterygoids). Additionally, it gives off fibers to the tensor tympani, tensor veli palatini, mylohyoid, and anterior belly of the digastric.

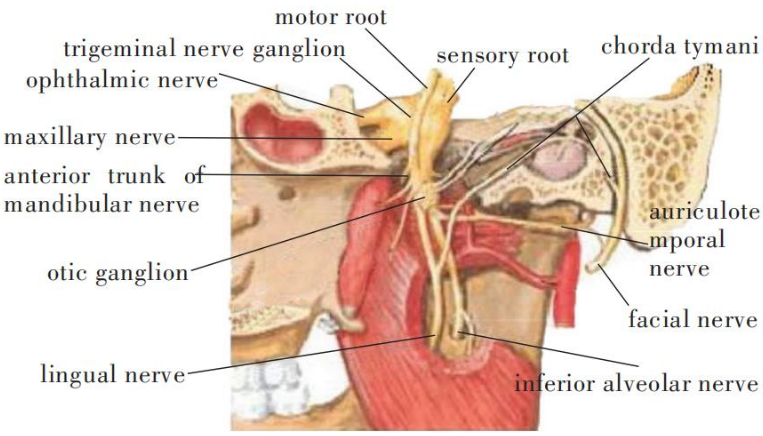

Figure 2. *Sensory and motor roots of the trigeminal nerve [3].*

Note: The motor root lies inferomedially to the sensory root, enters Meckel's cave in the middle cranial fossa. While the sensory root extends into the trigeminal ganglion, from which the ophthalmic, maxillary, and mandibular nerves arise and exit the cranial cavity. The motor root passes beneath the trigeminal ganglion (without entering it) before joining the mandibular nerve.

The trigeminal ganglion resides in Meckel's cave, a dural pouch in the middle cranial fossa situated at the trigeminal impression on the petrous temporal apex.The outer layer of Meckel's cave consists of dural and arachnoid sheaths that surround the trigeminal nerve root and ganglion, positioned lateral to the cavernous sinus. The lateral wall of the cavernous sinus, which adjoins Meckel's cave, contains the ophthalmic division of the trigeminal nerve, along with the oculomotor, trochlear, and abducens nerves (Figure 3).

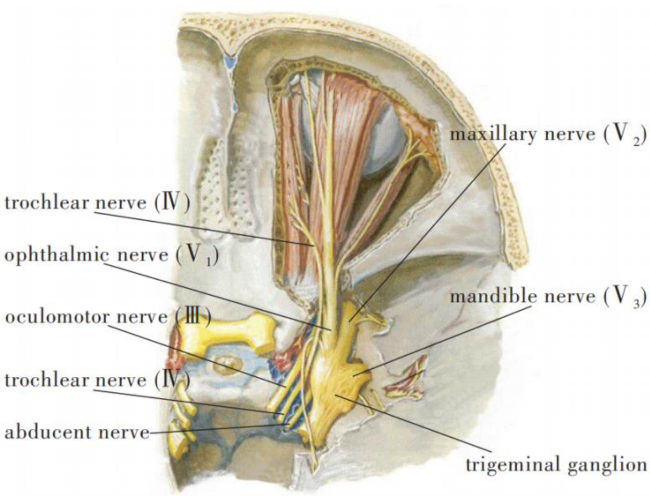

Figure 3. *Relation between the trigeminal ganglion and oculomotor nerve, trochlear nerve and abducens nerve.*

Note: The trigeminal ganglion resides within Meckel's cave, with the cavernous sinus situated medially. It is adjacent to the ophthalmic division of the trigeminal nerve, as well as the oculomotor, trochlear, and abducens nerves, which lie in the lateral wall of the cavernous sinus.

2. Mechanism of PBC for the Treatment of Trigeminal Neuralgia

Percutaneous balloon compression (PBC) involves percutaneous puncture of the foramen ovale using a balloon cannula, followed by insertion of a balloon catheter through the trocar into Meckel's cave. Contrast medium is then injected via the catheter to inflate the tip balloon within Meckel's cave, which compresses the trigeminal ganglion and nerve root. This compression selectively damages myelinated nerve fibers responsible for pain conduction, thereby achieving pain relief [1-2, 4] (Figure 4).

Currently, there is limited research on the analgesic mechanism of this surgery, and there is a lack of conclusive evidence-based medical evidence. Pure studies in rabbits have demonstrated that trigeminal nerves exhibit varying degrees of axonal injury and demyelination following PBC [5, 6]. Consequently, some scholars have proposed that the analgesic mechanism of PBC may involve the selective impairment of large myelinated nerve fibers—primarily responsible for pain conduction—while sparing unmyelinated fibers, which are mainly involved in mediating the corneal reflex [5-7]. This characteristic confers a unique advantage in treating pain within the distribution of the ophthalmic division (V1). However, other literature indicates that excessive compression during surgery may lead to postoperative weakening or loss of the corneal reflex, and even the development of keratitis [8-10].

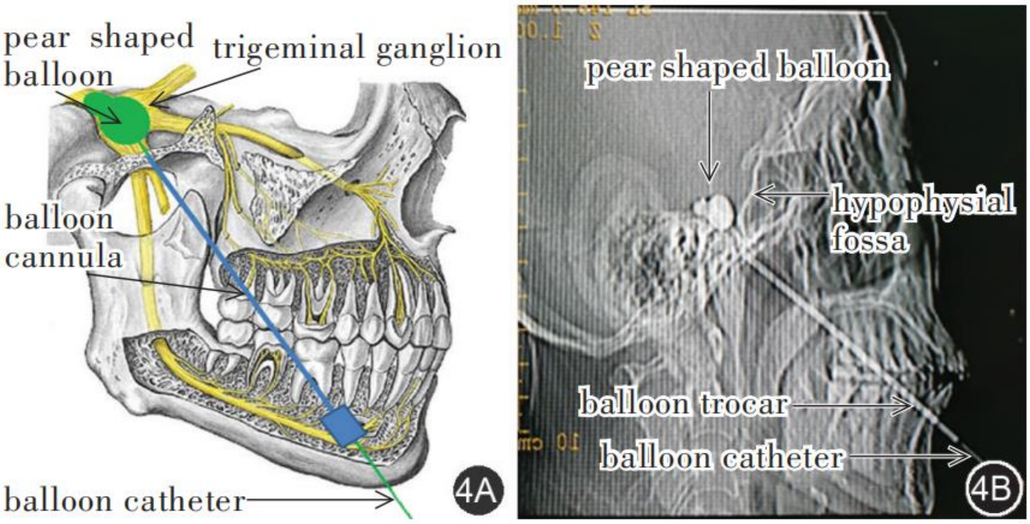

Figure 4. *Schematic diagram of balloon "pear shape" and lateral X-ray image.*

Note: Contrast medium injected into the balloon via a balloon catheter assumes a "pear shape," which compresses the trigeminal ganglion and nerve root.

3. Indications and Contraindications

3.1. Indications

3.1.1. Primary Trigeminal Neuralgia

Primary trigeminal neuralgia is the most common clinical subtype. The pain is strictly confined to the trigeminal nerve distribution area, characterized by paroxysmal recurrence. Each episode lasts from several seconds to several minutes, with complete remission during the interictal period. Precipitating factors include speaking, eating, toothbrushing, and face washing, and a "trigger point" is often present. Occasionally, it is accompanied by ipsilateral muscle twitching, lacrimation, and rhinorrhea. PBC has a well-established efficacy in treating primary trigeminal neuralgia. (Grade A recommendation)

Compared with microvascular decompression, PBC is more suitable for patients with the following characteristics: ① advanced age; ② poor general condition; ③ ineffective treatment or pain recurrence after microvascular decompression or other surgical interventions; ④ refusal of craniotomy [11]. Compared with radiofrequency thermocoagulation, PBC achieves better short-term pain relief and is more applicable to patients with involvement of the trigeminal nerve divisions V1, V2, or multiple divisions [12]. Additionally, PBC yields favorable outcomes for patients with recurrent primary trigeminal neuralgia following various previous surgeries [13, 14].

3.1.2. Secondary Trigeminal Neuralgia

Secondary trigeminal neuralgia, also known as symptomatic trigeminal neuralgia, refers to trigeminal neuralgia secondary to damage to the trigeminal nerve caused by various intracranial or extracranial organic lesions.

(i). Multiple Sclerosis (MS)

For trigeminal neuralgia associated with multiple sclerosis, PBC yields reliable therapeutic efficacy [15-19]. Its immediate pain relief rate is comparable to that achieved by radiofrequency thermocoagulation and glycerol injection (Grade A recommendation).

(ii). Trigeminal Postherpetic Neuralgia

Nowadays, there is a lack of large-scale studies evaluating the efficacy of PBC in treating postherpetic neuralgia. PBC is not recommended for patients with acute trigeminal zoster-associated pain. For patients with severe, intractable postherpetic neuralgia of long duration who have failed other treatment modalities, PBC may be a feasible option to achieve pain relief.

A case report described the use of PBC for 5-year frontal postherpetic neuralgia, with postoperative cranial nerve palsies involving the cranial nerves Ⅸ, Ⅹ, Ⅺ, and Ⅻ. This complication may be associated with reactivation of the varicella-zoster virus following surgery [20].

(iii). Tumor-related Trigeminal Neuralgia

Trigeminal neuralgia caused by tumor invasion of the trigeminal nerve may be considered for PBC to relieve pain in cases where the patient refuses craniotomy for tumor resection, or tumor resection carries excessive risk, provided that the Meckel’s cave structure remains intact and the therapeutic benefits outweigh the risks [21, 22].

(iv). Cephalofacial Pain Within the Trigeminal Nerve Distribution Area Caused by Tumor Invasion of the Head and Face

For patients whose pain remains inadequately controlled despite regular drug therapy, or who cannot tolerate drug treatment due to adverse reactions, PBC may be considered if diagnostic trigeminal nerve block achieves pain relief. Preoperative evaluation should include the patient’s prognosis, life expectancy, presence of infection, coagulation function, destruction of local anatomical structures, use of medications that increase bleeding risk, and the patient’s attitude [21, 23].

3.2. Contraindications

Puncture site infection, abnormal coagulation function, and patient refusal to undergo surgery (due to either inadequate understanding of the expected surgical efficacy or concerns about potential complications such as facial numbness and masticatory weakness) constitute contraindications.

4. Preoperative Evaluation

4.1. Preoperative Examinations

Standard preoperative laboratory investigations, including complete blood count, coagulation profile, and comprehensive biochemical panel, along with electrocardiography and thoracic imaging, are routinely performed. Preoperative cranial imaging (computed tomography or magnetic resonance imaging) should be performed to exclude secondary causes of trigeminal neuralgia. While magnetic resonance imaging can effectively delineate neurovascular relationships, it is not considered mandatory for PBC [24-28].

4.2. Assessment of Surgical and Anesthetic Risks

A detailed preoperative history and physical examination should be conducted to confirm the diagnosis. Patients must be counseled on the expected outcomes, potential complications, and recurrence rate.

5. Key Points of PBC

A detailed preoperative history taking and physical examination are essential to confirm the diagnosis. Patients must be counseled on the procedure's expected outcomes, potential complications, and recurrence rate.

5.1. Anesthetic Methods

Anesthesia can be administered as general anesthesia, awake regional anesthesia, or a combination of general anesthesia and regional anesthesia. During general anesthesia, airway control is achieved via endotracheal intubation or laryngeal mask placement. General anesthesia is associated with higher patient comfort; however, patients unable to tolerate general anesthesia would otherwise lose access to PBC treatment. Recent studies have demonstrated that trigeminal ganglion block anesthesia alone—where local anesthetics (e.g., lidocaine, ropivacaine) are injected into the trigeminal ganglion—is a safe and effective approach. This allows patients to remain awake with spontaneous breathing, eliminating the need for airway management [29, 30]. When technical conditions permit, a combination of general anesthesia and trigeminal ganglion block anesthesia may be selected [31].

5.2. Imaging Guidance Methods

PBC procedures require imaging guidance. Imaging is essential for guiding and confirming the entry of the balloon cannula into the foramen ovale, the intracranial positioning of the balloon catheter, and the filling shape of the balloon. The most common methods include C-arm or O-arm X-ray guidance. Additionally, techniques such as CT guidance and neuronavigation enable more precise placement of the balloon catheter into the foramen ovale and Meckel's cave [30, 32-38].

5.3. Operative Technique

The patient is positioned supine. Using the Hartel approach, the puncture site is marked approximately 2-3 cm lateral to the ipsilateral oral commissure. Additional marks are made at the center of the pupil and the midpoint of the zygomatic arch anterior to the antitragus to guide puncture of the foramen ovale.

The balloon cannula is directed toward the ipsilateral pupil in the coronal plane and advanced toward the midpoint of the zygomatic arch in the sagittal plane. Its trajectory is adjusted under imaging guidance until it enters the foramen ovale. The tip should be positioned at the external, middle, or internal opening of the foramen ovale to avoid excessive depth.

The balloon catheter is then advanced through the cannula into the Meckel's cave, extending 15-20 mm beyond the tip of the cannula. On oblique X-ray, the marking point at the catheter tip generally should not exceed 5 mm from the clivus (Figure 5); alternatively, it can be precisely placed at the level of theporus trigeminus on 3D CT imaging (Figure 6).

For balloon inflation, 0.5-1.0 mL of non-ionic contrast medium is administered via the catheter. The shape and position of the inflated balloon are observed on imaging, and injection is continued until obvious resistance is felt or balloon pressure is monitored.

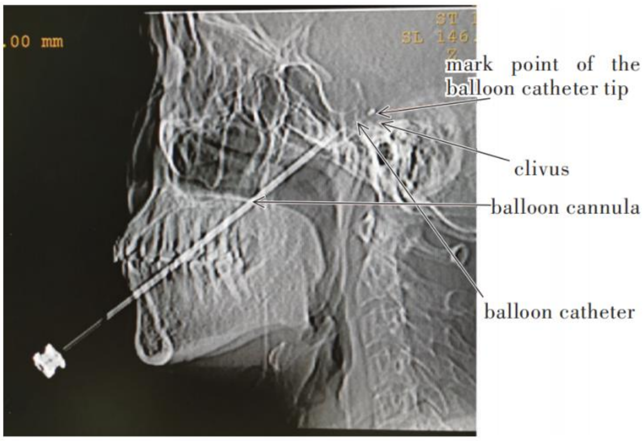

Figure 5. *Lateral X-ray image during PBC puncture in a patient with trigeminal neuralgia*.

Note: The marking point at the tip of the balloon catheter generally should not extend more than 5 mm beyond the clivus. (PBC: percutaneous balloon compression)

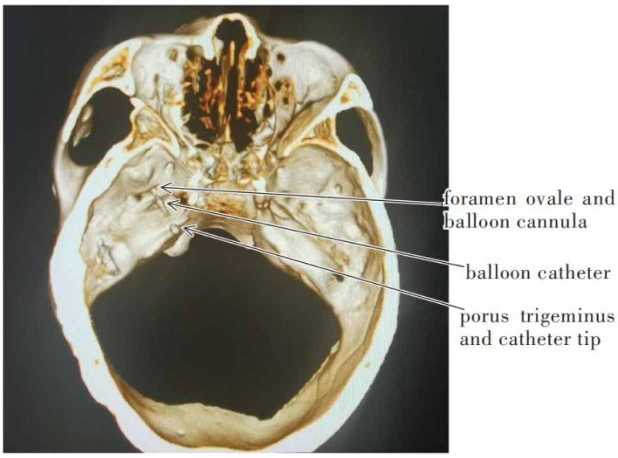

Figure 6. *3D CT imaging of the PBC puncture process in a patient with trigeminal neuralgia*.

Note: On 3D CT imaging, the tip of the balloon catheter is positioned at the level of theporus trigeminus. (PBC: percutaneous balloon compression)

The balloon catheter should be fully deflated prior to insertion. Depending on the catheter design, deflation can be achieved using either the classic single-lumen suction method or the more convenient direct contrast medium injection method (Figure 7). Following deflation, injection of contrast medium ensures more uniform compression of the trigeminal nerve.

Note: Push the contrast medium forward alone, and the air can be bleed the air through another pipeline

Figure 7. *Balloon catheter, Direct push injection type，dual exhaust structure catheter.*

5.4. Balloon Shape

On lateral X-ray images, the intraoperatively inflated balloon may assume shapes such as "pear-shaped," "dumbbell-shaped," "pear-like-shaped," or "oval-shaped" (Figure 8).

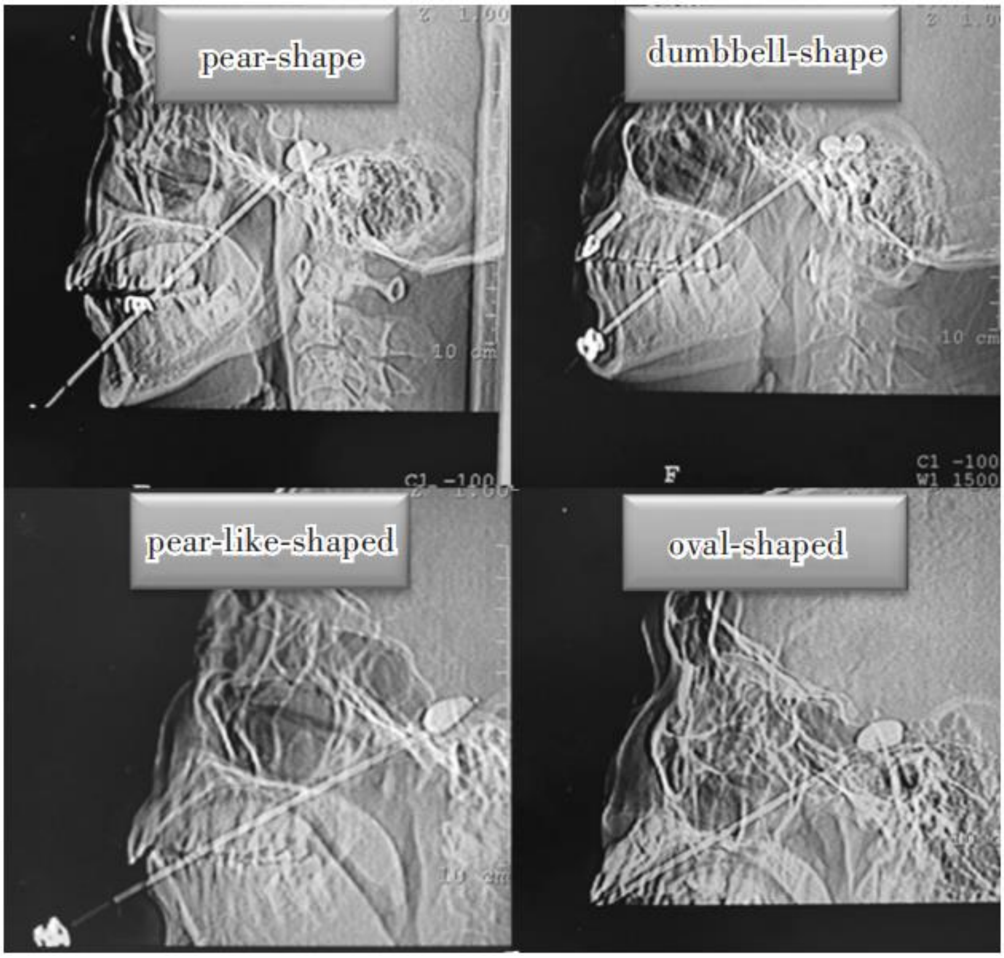

Figure 8. *Common balloon shapes following intraoperative contrast medium injection*.

Numerous studies suggest that a "pear-shaped" balloon with a nipple protruding into the posterior fossa on lateral X-ray indicates a successful procedure [2, 15, 29, 39-49]. This shape implies that the balloon is appropriately positioned within the Meckel's cave, with sufficient inflation, and its tip extends toward the trigeminal foramen. At this point, the balloon volume matches the capacity of the Meckel's cave, exerting targeted compression on the trigeminal nerve root and ganglion within the cave.

A "dumbbell-shaped" balloon indicates that the catheter is inserted too deeply or over-inflated. In this case, part of the balloon expands into the cerebellopontine angle cistern through the trigeminal foramen, extending into the posterior cranial fossa. When this occurs, emptying the contrast medium, slightly withdrawing the catheter, and reinjecting the medium can typically restore a "pear-shaped" configuration.

A balloon with an "oval" shape and no significant surface protrusion suggests that it has not entered or has not fully entered the Meckel's cave, failing to effectively compress the trigeminal ganglion. A definitive "pear shape" of the balloon confirms its location within Meckel's cave and correlates with significantly improved outcomes, achieving postoperative pain relief in nearly 100% of cases. In contrast, a "pear-like" morphology does not allow conclusive confirmation of intracave placement. In contrast, an “oval-shaped” balloon is associated with the lowest pain relief rate, ranging only from 37% to 53% [9, 36, 40, 50-54]. Balloon shape also has a significant impact on pain recurrence time: the pear shape is linked to longer pain relief duration and a lower 5-year recurrence rate (15.1% to 19.2%). Conversely, the pain-free period for the oval shape is significantly shorter than for other shapes, lasting only months to years [10, 38, 50]. However, since the studies reviewed did not standardize factors such as balloon volume, pressure, and compression time, the influence of these variables on efficacy cannot be excluded.

5.5. Balloon Volume and Pressure

The volume and pressure required to fill the balloon within the Meckel's cave depend on the patient-specific dimensions of the cave. Generally, a balloon volume of 0.4-1.0 mL generates sufficient pressure to yield significant resistance during injection [7, 15, 44, 50, 55-57]. With the balloon correctly positioned in Meckel's cave and the catheter secured, additional contrast medium directly increases pressure on the trigeminal ganglion [58].

Some studies have suggested that when the balloon is accurately positioned within the Meckel's cave, an inflation pressure of 600-1200 mmHg (1 mmHg = 0.133 kPa) can achieve reliable postoperative analgesia (Grade B recommendation) [59-62]. In contrast, pressures below 600 mmHg may result in inadequate compression of the trigeminal ganglion [5, 60, 63]. Clinically, although pressure varies with injection volume within a certain range, the two factors do not exhibit a linear relationship. This is because the Meckel's cave is not a rigid bony structure with a fixed enclosure, and intraoperative balloon pressure fluctuates within a specific range. To date, there is a lack of evidence-based medical data regarding the impact of intraoperative balloon volume and pressure on long-term surgical outcomes and complications.

5.6. Compression Duration

Currently, there is no absolute standard for compression duration in the literature. Some studies suggest that a 1-minute compression can achieve a definitive effect while significantly reducing the incidence of postoperative ocular complications, whereas compression exceeding 3 minutes may increase postoperative facial discomfort [10, 64]. Prolonged compression can lead to severe postoperative facial hypoesthesia, numbness, and even intolerable facial sensory abnormalities. Intraoperatively, factors such as individual patient differences, systemic condition, pain severity, and anatomical structure of the Meckel's cave should be considered. The recommended compression duration is less than 3 minutes [65], though it may be appropriately extended under special circumstances.

5.7. Surgical Instruments and Medications

In early PBC procedures, a sharp liver biopsy needle was used for puncture, which was associated with a high incidence of vascular injury. At present, a puncture trocar with a blunt inner needle is recommended, as it reduces the risk of significant structural damage to the puncture tract and prevents accidental rupture of the balloon catheter.

Rupture of the balloon after contrast medium injection may lead to intracranial leakage. Ionic contrast media (e.g., diatrizoate and iopamidol) with higher neurotoxicity are not recommended for intraoperative imaging. Instead, non-ionic contrast agents (e.g., iodopanol, iopromide, iohexol) are preferred [66]. Balloon rupture with contrast leakage is relatively rare. Several studies have indicated that skin prick tests (allergy tests) have limited value in predicting the risk of allergic reactions to iodine-containing contrast media. Therefore, pretest for contrast allergy is not recommended [66].

6. Evaluation of the Efficacy of PBC

6.1. Efficacy of PBC

Many studies indicate that PBC is a highly effective, preferred minimally invasive treatment for trigeminal neuralgia [67]. Compared with percutaneous radiofrequency thermocoagulation and glycerol injection, PBC achieves more persistent pain relief [17, 68]. In patients with primary trigeminal neuralgia, the immediate pain relief rate after PBC ranges from 85% to 99.5%, with a 5-year recurrence rate of 15.1% to 19.2% [69, 70]. The immediate pain relief rate and recurrence rate are associated with the surgeon's technical proficiency. The efficacy of PBC is comparable to that of microvascular decompression (MVD), and its recurrence rate is not higher than that of MVD [43, 71-73].

The incidence of major complications and mortality associated with MVD are higher than those with PBC (mortality: 0.2% vs. 0.1‰). The incidence of facial numbness and masseter weakness following PBC is significantly higher than that after MVD [sensory loss: 100% vs. 7%; masseter weakness: 56%-98.5% vs. 3%] [48, 72-75]. Owing to its superior safety profile, PBC offers greater advantages for patients with multiple comorbidities.

Balloon shape is a key factor influencing the efficacy of PBC in treating trigeminal neuralgia. During PBC, efforts should be made to adjust the balloon position until a "pear-shaped" configuration with a nipple protruding into the posterior fossa is achieved. Additionally, treatment outcomes are associated with factors such as balloon volume, pressure, compression duration, specific compression location within the Meckel's cave, and prior surgical history. [16, 76, 77]

6.2. Evaluation of the Operation Efficacy

Based on the Barrow Neurological Institute (BNI) Pain Relief Scale [11], a comprehensive assessment method was developed, which incorporates the degree of pain relief and severity of complications [11, 44, 78-81]. The specific method is as follows:

6.2.1. Evaluation of Postoperative Pain (E)

E-0: Completely pain-free

E-1: Occasional slight pain, self-controllable, without medication

E-2: Moderate pain, controllable by medication

E-3: Persistent pain, not controllable by medication, not cured

6.2.2. Evaluation of Complications (C)

C-0: No deficits, or only slight subjective complaints

C-1: Slight cranial nerve or cerebellar dysfunction, not bothersome for daily life

C-2: Both subjective and objective cranial nerve or cerebellar dysfunction, problematic for daily life

6.2.3. Total Evaluation of Results (T: Evaluation of Postoperative Pain+ Evaluation of Complications)

T-0: Excellent

T-1: Good

T-2: Fair

T-3 to T-5: Poor

7. Postoperative Management and Considerations

Trigeminal nerve injury may occur during puncture or balloon compression, which can manifest as hypoesthesia in the trigeminal innervation area postoperatively. After surgery, it is essential to monitor pain relief, as well as facial and lingual numbness. For patients with reduced orofacial sensation, advise them to avoid burns or accidental ingestion of foreign bodies. Additionally, check for weakened corneal reflexes; if present, measures should be taken to prevent corneal damage.

If the balloon shape is satisfactory but postoperative pain persists, patients may continue oral administration of preoperative anticonvulsant drugs at a lower dose than preoperatively; pain typically resolves gradually, a phenomenon referred to as "delayed relief." Literature reports indicate a delayed relief rate of approximately 2.9% [82, 83]. Some studies suggest that patients with delayed relief are more prone to recurrence [64]. For residual pain after PBC, options such as oral medications, nerve blocks, and radiofrequency therapy are feasible. If intraoperative balloon shape is unsatisfactory with persistent postoperative pain, repeat surgery may be considered in the absence of contraindications. For patients who were taking high-dose anticonvulsants (e.g., carbamazepine) preoperatively, gradual postoperative dose reduction followed by discontinuation is recommended.

8. Prevention and Management of Complications

8.1. Severe Intraoperative Hemodynamic Fluctuations

Hemodynamic instability is a common complication during PBC, with an incidence as high as 97.3% [64]. It typically occurs when the puncture needle enters the foramen ovale and during balloon inflation/pressurization. In severe cases, fluctuations in blood pressure and heart rate may even prevent successful balloon inflation and pressurization. Rarely, cardiac arrest has been reported, making this a major safety concern in PBC procedures [84]. Common hemodynamic changes include:

8.1.1. Hypotension and Bradycardia

These result from the trigemino-cardiac reflex (TCR) [85]. TCR is defined as a ≥20% reduction in heart rate and/or mean arterial pressure from baseline, triggered by traction or stimulation of the trigeminal nerve or its innervated tissues [86]; this is associated with vagal reflexes.

8.1.2. Hypertension and Tachycardia

This is attributed to intense pain during trigeminal nerve puncture or compression, linked to sympathetic reflexes.

8.1.3. Hypertension with Bradycardia

This is also frequently observed during balloon inflation and compression, thought to arise from the coexistence of vagal reflex (TCR) and painful sympathetic activation during

PBC [87, 88].

During general anesthesia, invasive intraoperative blood pressure monitoring is recommended to allow real-time observation of blood pressure changes [87, 88]. In cases of severe fluctuations in blood pressure and heart rate, the procedure must be halted immediately. Typically, blood pressure and heart rate will rapidly return to normal after cessation of surgical stimulation, requiring no additional intervention.

The key to successful surgery and anesthesia lies in implementing appropriate interventions based on the patient's specific condition. Pharmacological pretreatment and symptomatic management remain the primary approaches for addressing hemodynamic fluctuations. Atropine is recommended for preventing and treating vagal reflex-induced bradycardia, as it reduces the incidence of bradycardia and cardiac arrest; however, it does not prevent sudden hypertension [89-91].

Studies suggest that intravenous administration of sodium nitroprusside at the initiation of trocar puncture is an effective method to control acute hypertension. The dosage can be adjusted based on the severity of blood pressure elevation [91]. Trigeminal ganglion block, whether performed before trocar puncture or after advancement to the foramen ovale, can effectively maintain hemodynamic stability during PBC by reducing pain and blocking vagal and sympathetic reflexes (Grade B recommendation) [30, 31]. Although most cases of severe blood pressure and heart rate fluctuations can be prevented or managed, the risk of fatal cardiac arrest remains, which warrants close attention.

8.2. Cranial Nerve Dysfunction

Post-PBC hypoesthesia in the trigeminal distribution area occurs in 98%-100% of cases [10, 19, 41, 48, 52], attributed to trigeminal nerve puncture and balloon compression. The incidence of diminished corneal reflex after PBC (4%) is lower than that after glycerol injection (30%) [92]; if present, vigilance is required to prevent keratitis. Hypoesthesia typically diminishes gradually over time.

The incidence of masseter weakness after PBC is higher than that after percutaneous radiofrequency thermocoagulation or Meckel's cave glycerol injection [93], ranging from 6.3% to 100% across studies [94, 95]. This weakness is associated with injury to the trigeminal motor branch during puncture or compression, with varying degrees of impairment; recovery usually occurs within 2 to 12 months [75, 95].

Diplopia after PBC has an incidence of 2%-11%, primarily linked to damage to the IVth cranial nerve (trochlear nerve) or VIth cranial nerve (abducens nerve). It is more likely when the balloon is over-inflated toward the medial cavernous sinus in the middle cranial fossa and is mostly transient [96, 97]. Additionally, if the balloon catheter advances into the cerebellopontine angle of the posterior cranial fossa, inflation may compress the trochlear or abducens nerve. Thus, during PBC, every effort should be made to prevent the balloon's main body from extending beyond the clival slope on lateral X-ray. If this occurs, immediate adjustment is necessary. Caution is advised with dumbbell-shaped balloons to avoid over-inflation.

8.3. Herpes Simplex

The postoperative incidence of ipsilateral labial and/or buccal herpes simplex ranges from 14.7% to 35% [48, 95, 98, 99]. It typically develops 2-7 days after surgery, associated with reactivation of the herpes simplex virus in the trigeminal nerve [100]. Lesions generally resolve spontaneously within 1-2 weeks.There is no evidence-based support for prophylactic antiviral therapy before or after surgery. However, if postoperative herpes simplex occurs, antiviral medications may be considered.

8.4. Cerebrovascular Complications

Cerebrovascular complications, such as internal carotid artery hemorrhage, maxillary artery hemorrhage, subarachnoid hemorrhage, and cavernous sinus hemorrhage, are rare but potentially fatal. Thus, special attention is warranted [101, 102]. Excessively downward and medial puncture angles during foramen ovale access may pierce the lateral wall of the carotid canal, damaging the internal carotid artery—an extremely hazardous event. Subarachnoid hemorrhage can result from injury to intracranial vessels if the needle or balloon catheter is advanced too deeply. The use of precise imaging guidance and avoidance of repeated punctures can reduce the incidence of intraoperative vascular injury.

Abbreviations

PBC	Percutaneous Balloon Compression
TN	Trigeminal Neuralgia
MS	Multiple Sclerosis
MVD	Microvascular Decompression
BNI	Barrow Neurological Institute
TCR	trigemino-cardiac Reflex
GRADE	The Grading of Recommendations Assessment Development and Evaluation

Conflicts of Interest

The authors declare no conflicts of interest.

Appendix

The quality of research evidence was evaluated by The Grading of Recommendations Assessment Development and Evaluation, GRADE) working group. The evidence classification and the level of evidence was determined based on study design and other evidence characteristics.

Instructions for References

1. Reference including: clinical studies, randomized controlled trial study, cohort study, Meta-analysis paper, clinical report.

2. Literature was excluded: conference papers, studies with lack of efficacy assessment.

Classification of Reference value

I: Randomized controlled trial study.

II: Randomized controlled trial or retrospective study of a large number of patients.

III: Retrospective study.

1V: Summary of small group cases (total number of less than 100 cases), expert views.

Classification of Evidence-based medicine evidence for recommendation view

A: Highly recommended, at least two level I evidences.

B: Recommended, 1 level I evidence or 2 level II evidence.

C: Recommended or not recommended, 1 level II evidence or 2 level III evidence.

D: Not recommended, level IV evidence.

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