A Review of Percutaneous Treatments for Trigeminal Neuralgia

Jason S. Cheng, M.D.\textsuperscript{1}, Daniel A. Lim, M.D., Ph.D.\textsuperscript{1-3}, Edward F. Chang, M.D.\textsuperscript{1}, Nicholas M. Barbaro, M.D.\textsuperscript{4}

\textsuperscript{1}Department of Neurological Surgery, University of California, San Francisco, San Francisco, CA 94143, USA
\textsuperscript{2}Eli and Edythe Broad Center of Regeneration Medicine and Stem Cell Research, University of California, San Francisco, San Francisco, CA 94143, USA
\textsuperscript{3}Veterans Affairs Medical Center, University of California, San Francisco, San Francisco, CA 94143, USA
\textsuperscript{4}Department of Neurological Surgery, Indiana University School of Medicine, and Goodman Campbell Brain and Spine, Indianapolis, Indiana

Corresponding Author:
Jason S. Cheng, M.D.
University of California, San Francisco
Department of Neurological Surgery
505 Parnassus Ave, M779
San Francisco, CA 94143
Ph: (415) 353-3904
Fax: (415) 353-3907
chengja@neurosurg.ucsf.edu

Disclosure:
The authors have no personal financial or institutional interest in any of the drugs, materials, or devices described in this article.
Abstract

Background: Common treatments for trigeminal neuralgia (TN) include percutaneous techniques, microvascular decompression (MVD), and gamma knife radiosurgery (GK). While MVD is considered the gold standard for treatment, percutaneous techniques remain an effective option for select patients.

Objective: To review the historical development, advantages, and limitations of the most common percutaneous procedures for TN: balloon compression (BC), glycerol rhizotomy (GR), and radiofrequency thermocoagulation (RF).

Methods: Prior publications reporting clinical outcomes after BC, GR, and RF were reviewed and included. Operative technique was based on the experience of the primary surgeon and senior author.

Results: All three percutaneous techniques (BC, GR, and RF) provide effective pain relief but differ in method and specificity of nerve injury. BC selectively injures larger pain fibers while sparing small fibers and does not require an awake, cooperative patient. Pain control rates up to 91% at 6 months and 66% at 3 years have been reported. RF allows for somatotopic nerve mapping, selective division lesioning, and provides pain relief in up to 97% of patients initially and 58% at 5 years. Multiple treatments improve outcomes but carry significant morbidity risk. GR offers similar pain-free outcomes of 90% at 6 months and 54% at 3 years but with higher complication rates (25% vs. 16%) compared to BC. Advantages to percutaneous techniques include shorter procedure duration, minimal anesthesia risk, and in the case of GR and RF, immediate patient feedback.

Conclusion: Percutaneous treatments for TN remain safe, simple, and effective for achieving good pain control while minimizing procedural risk.

Key words: balloon compression, glycerol rhizotomy, percutaneous, radiofrequency thermocoagulation, trigeminal neuralgia

Running title: Percutaneous Treatments for Trigeminal Neuralgia
INTRODUCTION

Commonly performed percutaneous treatments for trigeminal neuralgia include balloon compression (BC), glycerol rhizotomy (GR), and radiofrequency thermocoagulation (RF). All of these procedures generally show effective initial pain relief and are relatively simple to perform. In all three treatments, pain relief derives from directed injury to the pain fibers in the trigeminal nerve. However, they do differ in their selectivity of trigeminal divisions and type of injury inflicted. BC and GR are less division-selective, whereas RF allows for a degree of dermatomal mapping prior to lesioning. On the other hand, BC is thought to selectively injure medium and large myelinated pain fibers while sparing small fibers.\(^1,2\) This selectivity may be especially useful in patients with first division pain, where sparing of the corneal reflex is an important concern.

Procedurally, all three techniques are generally safe and straightforward to perform in the operating room. BC does not require patient interaction during the procedure and is typically performed under general anesthesia for patient comfort, while GR and RF require patient cooperation and utilize short-acting agents. One potential complication intra-operatively is the trigeminal depressor response upon penetration of foramen ovale. This response is reported much more often in the BC procedure than in the other techniques.\(^3\) The resulting hypotension and bradycardia are transient, but may be significant and require administration of atropine and/or use of transcutaneous pacing.

Outcomes and rates of pain relief are generally good to excellent, though recurrence rates are significant, especially when compared to reported rates in other surgical procedures for TN.\(^4,5\) Efforts to identify predictors for long-term treatment success have been slow, and to date, few factors have been identified that hold up in repeated studies. One factor that has been identified is the character of the pain, whether it is typical or atypical. Typical TN is classically defined by 4 characteristics: (1) lancinating and electric pain in one or more trigeminal divisions; (2) defined trigger points; (3) defined triggers; and (4) memorable onset of TN. Atypical TN consists of patients (1) without definite trigger points; (2) with intermittent or persistent pain; (3) with concurrent numbness of dysesthesia; (4) those with other co-morbidities including multiple sclerosis (MS) and/or post-herpetic neuralgia. In all studies comparing typical versus atypical TN, atypical symptoms were a negative predictor of long-term treatment efficacy across all treatment modalities including RF, GR and stereotactic radiosurgery.\(^6-9\) In particular, those
patients with a dual diagnosis of MS and TN have higher recurrence rates and require more treatments compared to even the most refractory TN patients without MS.\textsuperscript{10, 11}

Ultimately, the decision of whether to use a percutaneous procedure and which percutaneous treatment to pursue is governed by many factors including which trigeminal division(s) is involved, whether the pain is typical or atypical, and the success of prior treatments. Complicating the decision is a medical literature comprised of mostly retrospective, cohort studies that make definitive comparisons between treatments challenging. In a review by Lopez et al., the authors highlight some of the deficiencies in reporting TN including varied nomenclature in characterizing TN symptoms, variations in procedural technique, and the lack of randomized-control trials directly comparing each modality.\textsuperscript{12} To increase standardization in reporting, Burchiel developed a modification of a classification system for TN based on the characteristics of the facial pain, and the Barrow Neurological Institute developed a pain scale to standardize the evaluation of pain relief post-operatively.\textsuperscript{13, 14} Hopefully these developments will continue to improve the consistency and quality of reporting in the medical literature and pave the way for new, randomized-controlled studies to effectively assess outcomes.

Until then, the percutaneous treatments for TN remain safe, effective, and simple procedures that offer excellent outcomes in the majority of patients.

METHODS

A Pubmed search of the clinical literature for publications describing techniques and outcomes after percutaneous treatments for trigeminal neuralgia was conducted from 1952 to 2013. Only English-language articles with the search term “trigeminal neuralgia” and at least one of the following keywords “balloon compression”, “glycerol rhizotomy”, or “radiofrequency thermocoagulation” were included. Additional search criteria included follow-up greater than 1 year. This produced 186 unique publications for inclusion and analysis.

RESULTS

Balloon Compression

Brief History

Percutaneous balloon compression originated from the early work of Shelden and Pudenz in the 1950s, though their initial intent was to decompress the ganglion\textsuperscript{3}. In 1952, Taarnhøj
decompressed the posterior gasserian ganglion in 10 patients via a subtemporal approach and reported excellent results\textsuperscript{15}. Continued work by Shelden, Pudenz, Taarnhøj and others led to the hypothesis that operative trauma rather than decompression per se likely caused the pain relief. Shelden’s technique of rubbing the posterior trigeminal root behind the ganglion led to the development of nerve compression therapies.\textsuperscript{16} However, it was not until 1983 that Mullan and Lichtor adapted the work of their predecessors to develop percutaneous balloon compression after recognizing that post-operative facial numbness correlated with better pain relief.\textsuperscript{17,18} In 1996, Brown et al., modified Mullan and Lichtor’s technique and advocated use of a blunt stylet to minimize vascular injury.

Animal models of trigeminal compression by Bennett and Lunsford in rabbits found nerve compression preferentially injured the medium and large myelinated pain fibers and work by Brown et al., showed this led to disruption of the ephaptic transmission of pain.\textsuperscript{1,2} Preservation of the small myelinated and unmyelinated fibers proved particularly beneficial in patients with first division symptoms, where damage to the corneal reflex remained a significant morbidity. In its present form, percutaneous balloon compression remains an effective treatment for TN. The ability to reliably spare important functions, such as the corneal reflex, remains to be shown in a large clinical trial.

**Procedure**

Because an awake or cooperative patient is not required, balloon compression is generally performed under general anesthesia, though intravenous anesthesia combined with local anesthesia at the ganglion level has also been reported.\textsuperscript{19,20} After induction of anesthesia, a transcutaneous or transesophageal pacemaker is established and tested in anticipation of stimulating the trigeminal depressor response. These transient episodes of bradycardia and hypotension may be significant and occur upon engagement of the foramen ovale with the stylet and during balloon inflation.\textsuperscript{21,22} Atropine is typically not administered to allow for monitoring of trigeminal compression. Visual confirmation of needle and balloon placement during the procedure is accomplished with flouroscopy.

The patient is positioned supine with a neck roll to achieve 15° of extension. The initial landmarks include a skin insertion point 2.5 cm lateral to the corner of the mouth and a trajectory towards a point in line with the medial ipsilateral pupil and 2.5 cm anterior to the external
auditory canal. A 14-gauge needle is inserted along the target trajectory and advanced to 1 cm behind the posterior clinoid along the angle of the clivus. Härtel guidelines and lateral view fluoroscopy aid in positioning a 14-gauge needle to just outside foramen ovale. Figure 1 illustrates the trajectory and insertion technique using these landmarks. The formaen ovale is then entered, and confirmed with either return of CSF or via fluoroscopy as seen in figure 2. Engagement of the foramen frequently elicits a trigeminal depressor response and contraction of the masseter and pterygoid muscles. \(^{22}\)

Once the needle reaches the skull base, the fluoroscope is positioned for a submental view to provide direct visualization of the foramen ovale. A thin K-wire stylet is passed into the needle and positioned at the entrance to Meckel’s cave. The needle is subsequently removed and a properly sized stylet and blunt cannula are passed over the K-wire. Next, the K-wire is removed and the stylet and cannula are advanced into the foramen ovale using fluoroscopic guidance in the anterior-posterior plane. Centering the petrous ridge in the radiographic image provides the optimal visualization. The inner stylet is then removed and a 4-Fogarty embolectomy catheter is passed with its tip in the porous trigeminus along the edge of the petrous bone and dorsal to Meckel’s cave. Placing the catheter in the center of the porous targets the second division or multi-division pain. Lateral placement more effectively treats third-division pain, and medial placement isolates the first-division. A lateral view confirms proper localization. The balloon is inflated with iohexol to a pressure of approximately 1,000 – 1,200 mmHg for 60-90 seconds. A second trigeminal depressor response may be seen at this time. Classically, the balloon attains a desirable “pear shape” once fully inflated, bounded inferiorly by the petrous bone and superiorly by the dural edge. In the event the balloon does not attain the desired “pear shape” or pressure, a larger balloon may be used during the same or subsequent procedures. Accurately recording the balloon size, location, and shape provides data for planning subsequent treatments, if necessary. After the desired compression, the cannula and balloon catheter are removed and pressure is held at the skin puncture site.

Discussion

Balloon compression offers excellent initial pain relief, with rates as high as 94% in one study of 50 patients by Brown et al.\(^{23}\) Actuarial rates of complete pain relief were 91% and 69% at 6-months and 3-years, respectively, and others have reported similar rates of pain relief.\(^{19, 24-27}\)
The procedure may be advantageous in patients with first-division pain given the reports of selective sparing of the small fibers carrying the corneal reflex.\textsuperscript{23} However, it is not without significant limitations. Patients unable to tolerate general anesthesia or those with significant cardiac histories are generally poor candidates. Dysesthesias rates vary from 10-20\% in the reported literature, and severe numbness occurs in approximately 20\% of patients.\textsuperscript{4, 28, 29} Masseter weakness has also been reported, but typically resolves within 12 months.\textsuperscript{4} Meningitis (2.6\%) and cranial nerve deficits (1.5\%) are less common.\textsuperscript{4, 23} Recurrence rates are high (average 26\% with a mean-time to recurrence of 18 months) when compared with short-term recurrence rates reported for other TN surgical procedures.\textsuperscript{23}

There are several possibilities for why the procedure might not work initially or why pain may recur. First, the size of Meckel’s cave varies significantly between patients, and a successful outcome depends heavily on the relative size of Meckel’s cave and the balloon.\textsuperscript{30} In patients with large Meckel’s caves, even the largest standard balloon may not produce sufficient compression to achieve a therapeutic outcome. To address this limitation, Goerrs and colleagues have designed and tested a series of larger cannulas and several balloon approaches to achieve better compression in these patients.\textsuperscript{31} Initial studies reveal significantly improved compression pressures and balloon shapes with the modified approaches, though a detailed outcomes report remains to be published. A second variable requiring further investigation involves the pressure of balloon compression. Higher pressures are associated with higher rates of dysesthesias, severe numbness, and masseter weakness, while lower pressures often produce little pain relief and high-rates of recurrence.\textsuperscript{32, 33} Brown et al., employed continuous balloon pressure monitoring in an attempt to quantify the preferred pressure and compression times to maximize pain relief while minimizing ill-effects.\textsuperscript{34} They found that a target compression pressure between 750-1250 mmHg for 1.15 minutes had the greatest efficacy in their retrospective study of 56 patients. Compression time is a third variable that affects pain-relief, and treatments ranging from 1 to 7 minutes have been reported with the degree of sensory loss directly correlated to length of treatment.\textsuperscript{24, 35} Further, Montano et al., examined additional prognostic factors for determining the efficacy of BC in patients with multiple sclerosis. Significant factors included pain in only one division, absence of prior interventions, a compression time of less than 5 minutes, and a pear shaped balloon\textsuperscript{36}.
Despite the high recurrence rates and inability to control the degree of numbness, balloon compression may offer advantages over GR or RF: (1) It may be performed under general anesthesia which optimizes patient comfort, (2) It does not require a cooperative patient, and (3) It is selective for large and medium myelinated fibers and may preserve the small fibers carrying the cornea reflex. Balloon compression thus remains an effective treatment for TN.

**Glycerol Rhizotomy**

**Brief History**

Glycerol rhizotomy developed as a chance finding in 1981 when Häkanson and colleagues were working to pioneer use of stereotactic gamma radiation for TN. They used a glycerol carrier to inject the tantalum dust into the trigeminal cistern and discovered that injection of the medium alone caused relief from pain. Further studies found this likely due to demyelination and axonal fragmentation. Since its development, the technique has remained relatively unchanged with only minor modifications.

**Procedure**

Glycerol rhizotomy does not require an awake patient and thus deeper anesthesia may be used for patient comfort. Similar to the other procedures described, a trigeminal depressor response is seen in up to 20% of patient during either penetration of the foramen ovale or injection of glycerol. Consequently, atropine may either be pre-administrated or injected at the first sign of bradycardia. The patient is positioned supine on the operating table such that fluoroscopic imaging is possible. Fluoroscopy is placed in the anterior-posterior plane and the head is positioned such that the petrous ridge is level with the inferior orbital rim. The needle entry point and trajectory to enter foramen ovale remains identical to the procedure described previously for balloon compression. However, a 20-gauge needle is used for glycerol rhizotomy. Once the needle is correctly positioned, the patient is then elevated to the sitting position. A contrast cisternogram is performed with iohexol to assess the volume of the trigeminal cistern and to determine the appropriate volume of glycerol. Expected volumes range from 0.25 to 0.4 ml. Drainage of contrast may be via passive flow out of the cistern or by returning the patient to the supine position. The injection of glycerol is then performed with the patient in a sitting position. For multi-division pain the full volume of glycerol is injected. For first-division pain,
the glycerol is injected prior to the complete drainage of contrast material. Glycerol is relatively less-dense than contrast, and thus will rise and layer above the contrast, selectively treating the first division. Similarly for isolating third-division pain, only 1/3 of the cisternal volume of glycerol is used. After injection, the needle is removed and the patient is to remain in the sitting position for 2 hours to prevent leakage of glycerol into the posterior fossa. Afterwards, the patient may be discharged home if stable or observed in the hospital overnight.

Discussion

Initial pain relief is >90% in one recent study of 3370 patients. Complete pain relief at 6 months and 3 years ranges from 78-88% and 53-54%, respectively. Commonly reported complications from GR include dysesthesias (average 8.3%), corneal numbness (average 8.1%), and masseter weakness (average 3.1%). Herpes labialis has also been reported as high as 12%. In one study by Pollock, the only statistically significant predictor of positive treatment outcome was pain during the glycerol injection (p < 0.01, univariate analysis). A multivariate analysis in the same study found that facial pain during injection correlated with good pain outcome (RR=1.02; 95% CI 0.26-1.77; p < 0.01), while constant facial pain predicted a poor prognosis (RR = 1.13; 95% CI 0.06-2.20; p = 0.04).

Similar to other studies, pain relief correlates with degree of numbness, though pain relief without sensory disturbance is frequently touted by proponents of glycerol rhizotomy. In a study of 112 patients by Lunsford and Bennet, 23% of patients had altered facial sensation post-operatively while additional studies reported rates as high as 49% and 53%. In fact, some experts such as Burchiel find that the success of glycerol rhizotomy depends on some degree of sensory loss.

Compared to RF, GR offers similar actuarial rates of pain relief (24.8% versus 29.2%) with similar complication rates. Compared to BC, however, GR had higher complication rates (24.8% vs. 16.1%) in one study and lower complication rates in another (11% vs. 26%), with similar pain relief outcomes in both. Pain recurrence rates up to 35% have been reported, with the majority (21%) occurring within 5 years of initial procedure. In one study, repeat GR provided pain-free relief without medications of 79% at 25 months with prior successful GR being a positive predictor of repeat success.
Radiofrequency Thermocoagulation

Brief History

Radiofrequency lesioning was first developed in 1913 by Réthi with attempts to electrocoagulate the trigeminal nerve and gasserian ganglion rootlets. However, it was not until 1975 that Sweet and colleagues pioneered the use of thermocoagulation to target the trigeminal rootlets that the procedure was shown effective for pain relief. The initial use of this technique resulted in a significant percentage of patients with dysesthesias, which dampened enthusiasm for widespread use. Further research led to the development of additional improvements to minimize unwanted side-effects. These included temperature monitoring, use of short-acting anesthetic agents, and electrical stimulation with awake-patient feedback. Further refinements by Nugent and Rovit added the use of a finer cordotomy electrode and neuroleptic anesthetic agents to allow for repeated small lesions. Later, the introduction of a curved thermistor-tipped electrode allowed increased selectivity of lesioning. Through this work it was also recognized that less dense lesioning reduced dysesthesias with no reduction in pain relief.

As a consequence of these pioneering developments, recent studies report pain relief as high as 90% with recurrence rates of up to 25%. Yet despite these many refinements, radiofrequency thermocoagulation still carries major morbidity as compared to other surgical treatments for TN.

Procedure

Patients are awake during portions of the procedure and cooperation is critical during the stimulation phase to ensure correct placement and localization of the RF lesion. Pre-operatively, patients must learn how to localize and designate where they perceive facial stimulation, which may be more difficult during the procedure due to the lingering effects of anesthesia. In the OR, they are positioned as described previously and C-arm fluoroscopy is positioned to assist in the proper needle placement to foramen ovale. In some cases, CT control and neuronavigation have also been reported. Induction is performed typically with a short-acting neuroleptic analgesia such as Propofol, but a combination of alfentanil and midazolam has also been used. After induction, a needle with an obturator is introduced into the foramen ovale, during which time a transient bradycardia may occur. Atopic placement in the foramen is confirmed with fluoroscopy, and lateral views should confirm that the tip of the needle does not reach beyond
the petroclival junction (see figure 2). Once position is confirmed, the obturator is removed and the electrode is introduced. The patient is awakened and sensory and motor responses are tested. A detailed mapping then provides the optimal locations for lesioning in order to maximize the pain relief (by overlapping new sensory deficits with maximal pain regions) while minimizing dysesthesias and motor weakness. Electrical stimulation is typically achieved at 0.2 to 1 V (50 Hz, 0.2ms). The stimulating electrode is then replaced with the thermocouple and lesions are made at a maximum of 0.5 V at 5 and 75 cycles per second at 55-80° C for 30-120 seconds. Individual techniques vary from use of a single lesion to the use of additional lesions with the goal of producing hypalgesia in the target branch. The hospital course is typically short, with discharge anticipated the same or next day.

Discussion

Radiofrequency thermocoagulation is a procedure that offers high initial pain relief with rates reported as high as 97.6% in one study of 1561 patients by Kanpolat et al. In the same study, Kaplan-Meier analysis for pain-free survival in patients treated with a single RF procedure showed complete pain relief in 57.7% of patients at 60 months and 42.2% at 180 months. Pain relief was defined as pain-free with no medications. When patients treated multiple times with RF were included, those rates increased to 92.1% at 60 months and 97.3% at 180 months. Two smaller studies have reported Kaplan-Meier recurrence rates ranging from 7.8 to 25% at 11.6 and 14 years, respectively. In the study by Taha et al., it was also noted that pain recurrence correlated with degree of post-operative sensory deficit. Those with mild hypalgesia recurred sooner (within 4 years) compared with those with dense hypalgesia and analgesia. The latter group reported 95% satisfaction rates even at 15 years, though these included those patients treated a second time.

The main limitations preventing more widespread use of RF are the frequency and severity of side-effects. Masticatory weakness has been reported as high as 29% in one study, and rates of dysesthesias range from 1-11% (average 3.7%), and corneal numbness from 3-20% (average 9.6%). These side-effects may be due to (1) significant differences in the somatotopic organization of the trigeminal nerve between individuals and the challenge of accurate mapping prior to lesioning and (2) irreversible damage of small, unmyelinated pain
fibers at the coagulation temperatures of 55-70° C compared with balloon compression, which selectively spares these same fiber types.23, 69, 70

In an effort to improve the efficacy of RF, Karol and colleagues developed a quadripolar electrode for increased mapping accuracy. Their invention utilizes a computerized system to record and explore verbal responses from 34 facial subsegments (as compared to the standard three). Using a self-designed quadripolar electrode for stimulation of the post-gasserian fibers, the accuracy of their somatotopic maps allows them to decrease their lesion size to 1.5x3mm. This considerably reduces unnecessary and unwanted injury, yielding improved outcomes.71

Other efforts have focused on improving lesioning accuracy through use of CT and neuronavigator control.61-63 These preliminary studies suggest that improved imaging and needle localization may lead to lower rates of complications. In the neuronavigator study by Xu et al., the authors compared the efficacy of neuronavigator versus standard fluoroscopy in 54 patients. Recurrence rates for the neuronavigator group at 12, 24, and 36 months were 85%, 77%, and 62% respectively while the control group fared worse at 54%, 40%, and 35% at the same time points. While additional, prospective studies are needed, these initial findings suggest use of neuronavigator-guided control improves complication and recurrence rates.

While better imaging may improve lesion accuracy and recurrence, Fraioli et al., reported that recurrence also depends on the site of the lesion within the division. In a study of 158 patients with isolated third division pain, the authors noted lower rates of recurrence when the thermocoagluation target is at the gangliar-retrogasserian site versus between the 3rd division and gasserian ganglion.64

In comparison with the other operative procedures for trigeminal neuralgia, RF offers the following advantages over other percutaneous techniques: (1) Recurrence rates are lower compared to glycerol rhizotomy, and (2) it is more selective than balloon compression, allowing for isolated division therapy.4 Further, in patients with the dual diagnosis of TN and MS, in whom higher recurrence rates and treatment failure have been reported, RF has proven to be an effective and safe treatment.10, 72

**DISCUSSION**

The three percutaneous techniques described represent some of the earliest surgical treatments for trigeminal neuralgia. They are collectively regarded as safe and effective in the
properly selected patient. Since their development, additional treatment modalities have been developed, notably microvascular decompression (MVD) and gamma knife radiosurgery (GK)\textsuperscript{73-76}. While not the subject of this review, these additional techniques provide alternative approaches for the skilled practitioner.

MVD represents a non-destructive surgical technique for relieving trigeminal nerve compression at the root entry zone, most often due to vascular compression\textsuperscript{74,77,78}. Common offending vessels include the superior cerebellar artery or a bridging vein and may be identified on pre-operative MRI\textsuperscript{79-82}. Intra-operatively, the vessel is carefully freed from the nerve and held away using Teflon or another non-absorbable material. Good long-term control rates (pain free, off medication) have been reported and range from 65-84\% with an average follow-up of 6 years\textsuperscript{83-86}. Associated risks of the procedure include general anesthesia (death 0.3\%), sensory loss (5-10\%), and cerebrospinal fluid leak (7\%) with an average hospitalization of 2-4 days\textsuperscript{74,83,87}.

In addition to MVD, GK radiosurgery has also gained in popularity in recent years due to its non-invasive approach. While long-term studies are currently ongoing, targeted doses of 70-90 Gy to the trigeminal root entry zone have demonstrated good pain control rates of 50-75\% at 5-year follow-up\textsuperscript{88,89}. Increasing radiation doses provide more effective pain relief but are associated with increased rates of bothersome paresthesias or numbness ranging from 10-32\% in published studies\textsuperscript{8,88-90}. Refractory cases may be re-treated, though multiple treatments carry increased risk of nerve dysfunction.

In the properly selected patient, each of the three procedures described in this review along with MVD and GK may provide good long-term pain control while minimizing bothersome side-effects. To date, no randomized clinical trial exists comparing the efficacy and long-term outcomes of these procedures. While retrospective case-control series provide evidence for the outcomes of a given procedure, significant differences in procedural technique and reporting of outcomes make direct comparisons between studies difficult.

As with all procedures, patient selection remains an important process in determining clinical outcomes. The first component of patient selection comprises patient preference and tolerance for risk and side effects. In a 2007 paper by Spatz and colleagues, the authors surveyed 156 patients with TN treated either surgically or with medication alone\textsuperscript{91}. 76\% of the study participants had undergone surgical intervention consisting of either MVD, BC, GR, or RF. In
their utility analysis, patients were queried for procedural preference, tolerance for numbness, and temporary and permanent complications. On average, patients preferred MVD just narrowly over BC, GR, and RF. Most patients opted for medical management last. However, when their tolerance for complications and side effects were taken into account, it turned out that BC would have been their preferred treatment despite their own perceived choice. These findings highlight the challenge of managing patients’ expectations with published outcomes.

The second component of patient selection focuses on the underlying pathophysiology of trigeminal neuralgia. While no clear cut algorithm exists, from our experience there are several sub-populations of patients that may benefit from a given procedural choice. In our 2005 study and others, we studied patients with the dual diagnosis of multiple sclerosis and TN and compared treatment response. We concluded that patients with MS require significantly more treatments than even the most medically refractory non-MS patients, and of the treatment modalities available, radiosurgery provides the longest lasting and most effective therapeutic modality\textsuperscript{10}. Another sub-class of patients with good evidence includes cases of TN with clear vascular compression observed on MRI. In these instances, microvascular decompression provides an effective strategy to relieve the cause of the pathology with minimal risk of induced parasthesias\textsuperscript{82, 92, 93}. In the remainder of cases for which no clear etiology exists, there remains a lack of class I evidence to aid in treatment selection.

In addition to patient considerations, the practicing neurosurgeon must also consider his/her familiarity and skill with the described methods. In particular, the proper positioning of the Hartel needle may be a source of anxiety and consternation for some, especially in an awake patient. Intra-operative guides such as C-arm fluoroscopy or the employment of neuro-navigation may provide a reassuring aid early on to become facile with the technique. This learning curve for percutaneous techniques more broadly applies to all aspects of neurosurgery, and the balance between patient outcomes and procedural training remains a challenging topic. In a 2003 study by Kalkanis et al., the authors assessed the link between hospital and surgeon volume with clinical outcomes. In their report, they evaluated surgical outcomes after 1,326 cases of microvascular decompression at low (< 20 cases per year) and high (> 29 cases per year) volume centers. Their results showed a significant improvement in clinical outcomes and fewer complications at higher volume centers and higher volume surgeons, suggesting experience and case volume play important roles in patient outcomes\textsuperscript{94}. 
This review highlights the need for future high quality, multi-institutional trials comparing the efficacy of the described surgical techniques for trigeminal neuralgia. Until then, practitioners will continue to rely on retrospective evidence, patient preference, and procedural familiarity to guide decision-making.

CONCLUSION

The percutaneous treatments for TN remain safe, effective options that provide excellent initial pain relief. While microvascular decompression remains the gold standard in treatment and stereotactic radiosurgery offers promising results, there is still a place for BC, GR, and RF in the treatment of TN.

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FIGURE LEGENDS

Figure 1: Artist’s illustration depicting needle insertion into foramen ovale for radiofrequency thermocoagulation. (A) patient position and needle trajectory. 3-dimensional paramedian (B) and lateral (C) views of needle trajectory through the buccal tissue to reach foramen ovale. Care is taken to not enter the oral cavity. (D) Final needle position at the trigeminal ganglion. Careful manipulation allows for selective lesioning of individual trigeminal divisions.

Figure 2: Intra-operative lateral x-ray demonstrating proper position of needle at foramen ovale.
