Radiofrequency Gangliolysis of the Trigeminal Nerve for Trigeminal Neuralgia

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Chapter
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Abstract

RFL is an effective treatment for TN. Major complication rates are low. The most likely complications are related to the extent and density of lesion created and has been mitigated by the treatment strategy of minimizing the amount of hypoesthesia created during thermoablation.

While acutely effective, RFL has a treatment half-life of about 3 years. However, the lesion can be repeated several times. Allowing for multiple procedures, pain-free results for TN treated with RFL can be as high as 80 % over 6 years. Given that this is a minimally invasive, well-tolerated outpatient procedure with low risk of complication, this is a very reasonable option for the management of TN.

Given that RFL is a safe and effective treatment for TN, it is important that the surgeon or physician treating facial pain maintains the ability to offer this treatment.

Keywords

Trigeminal neuralgia Tic douloureux Trigeminal ganglion Radiofrequency gangliolysis Trigeminal nerve

Introduction and History

Trigeminal neuralgia (TN) is characterized by lancinating, paroxysmal, excruciating pain in one or more divisions of the trigeminal nerve. It is usually unilateral. The onset is generally recalled by the patient and should not be associated with trauma or a surgical procedure of the face or dentition. Pain within the affected divisions can be generated spontaneously or triggered by light touch, wind, changes in temperature, or movements such as speaking or chewing. It is episodic with clear-cut pain-free intervals and may often enter remission for days, weeks, or even years. During pain attacks, patients may be left unable to eat or drink, speak, shave, or wash.

While historical descriptions of facial pain have been in existence since at least the time of Hippocrates [16], it was not until the late eighteenth century that Andre and Fothergill, a French surgeon and English physician, independently described the distinct clinical entity known as “tic douloureux” or “Fothergill disease”; neither localized the disease to the trigeminal nerve [9, 16]. It was not until Charles Bell described the distinct functions of the trigeminal and facial nerves that trigeminal neuralgia would be defined as we know it today [9, 16].

The pathophysiology underlying development of TN remains unclear. In 1934, Walter Dandy surmised that compression of the nerve by tumor or artery might serve as a cause [11]. Jannetta’s 1967 paper postulating neurovascular compression (NVC) as the root cause of TN [20] and the remarkable success of microvascular decompression (MVD) as a treatment for TN [2] have led to the unfortunate conflation of NVC with TN. This belief persists in spite of the fact that TN clearly occurs and recurs in the absence of NVC [28] and that NVC of the trigeminal nerve is seen in up to 17 % of asymptomatic patients [33]. While NVC cannot be the sole cause of TN, it is likely that some injury to the nerve (with or without NVC) causes demyelination and reinforces excitability [13, 14, 23, 26]. Subsequently, more widespread gray and white matter changes may occur [12, 27, 29, 36].

The primary treatment for TN is medical. The use of anticonvulsants to treat trigeminal neuralgia was introduced by Bergouignan [3] in 1942, and since the introduction of carbamazepine by Blom [4] in 1962, medical science has not found a more effective medical treatment for TN than the sodium channel-blocking antiepileptics [54, 57]. Oxcarbazepine may have a more favorable side effect profile than carbamazepine, which is significant because treatment failure with medications is most often related to intolerance of the treatment rather than treatment failure [15]. There are few studies focusing on effectiveness of medical treatment over time. However, 20–30 % of patients fail medical treatment acutely due to side effects [15, 54], with another 10 % failing over the long term [15].

Surgical treatment for TN can be classified as ablative or non-ablative. A pain-free patient off of medications is considered a success. It is paramount to remember that all of these treatments have a half-life; that is, pain recurrence is not a complication but an expected consequence of TN. The duration of pain-free outcomes must be considered when presenting treatment options to patients and making the clinical decision of what treatment option to pursue. These factors will be discussed in more depth later in this chapter.

MVD is nondestructive and is the most effective and durable treatment for TN [2, 43]. Initial response to treatment is excellent. At 10 years, the rate of continued freedom from pain ranges from 50 to 85 % [2, 7, 43]. However, it is the most invasive procedure, requiring a craniotomy, posterior fossa exploration, and its attendant hospitalization and recovery time. Moreover, this surgery is not possible when there is no NVC.

All other procedures to treat TN are ablative in nature. Alternatives to MVD during a posterior fossa exploration are directed at the trigeminal root entry zone (REZ) and include partial sensory rhizotomy (PSR), nerve compression, and internal neurolysis. These interventions are less successful and less durable [21, 31, 38, 39, 53].

Stereotactic radiosurgery (SRS) is also used to ablate the REZ and is far less invasive than posterior fossa exploration. It is often pursued in patients where no NVC is noted or when medical comorbidities significantly increase surgical risk. It is also the least effective surgical treatment for TN [32, 51, 52]. This is particularly notable insofar as most studies of SRS consider improvement in pain (while on medications) a treatment success, in contrast to the complete abolition of pain that is the goal of craniotomy or percutaneous procedures.

Other commonly employed ablative treatments employ a percutaneous approach to the trigeminal ganglion. Methods for ablating the ganglion include radiofrequency gangliolysis, balloon compression, and glycerol gangliolysis. The efficacy and durability of these percutaneous treatments are in large part equivalent, with excellent initial results comparable to MVD, but a significantly shorter duration of pain relief [6, 8, 30].

Radiofrequency gangliolysis was first described by Sweet in 1974 [44]. Other percutaneous techniques for trigeminal gangliolysis include chemoneurolysis by glycerol injection, first described in 1981 by Hakanson [17], and balloon compression of the ganglion within Meckel's cave, reported by Mullan in 1983 [35]. These other techniques employ the same approach to the ganglion through the foramen ovale. The remainder of this chapter will focus on the first of these approaches.

The extraoral, percutaneous approach to the trigeminal ganglion was first described in 1914 [18] and is still in use today [37]. The use of electrocautery to ablate the ganglion was described by Kirshner in 1931 [24], but this technique was fraught with complications, as it employed monopolar current [9]. It was not until the introduction of radiofrequency thermoablation by Sweet, with the ability to provide precise temperature control during lesion creation, that the technique became safer and gained in popularity [44]. Further development of this procedure included the addition of short-acting anesthesia, stimulation mapping, and curved, guidable electrodes that allowed even more precise lesions [9].

Today, the goal of radiofrequency gangliolysis is to provide a selective destruction of pain-sensing fibers within the preganglionic fibers of the trigeminal nerve, providing instant pain relief in an outpatient setting. It has the benefit of allowing intraoperative confirmation of the site and density of lesion creation, making possible the specific targeting of one or more divisions of the nerve and selectively destroying the Aδ and C-fibers thought responsible for conveying the painful sensations in TN while minimizing loss of other modes of sensation [19]. It does not require general anesthesia and is minimally invasive, thus being safe in patients with medical comorbidities, and patients are generally discharged the same day.

Technical Aspects and Equipment

Radiofrequency gangliolysis can be performed with an RF generator with the ability to measure impedance, perform stimulation, and measure temperature. The authors use a Cosman® RFG-1A mode RF generator [10]. Impedance measurements can be useful in determining whether the electrode is within the ganglion or in CSF. Impedance within the ganglion is 150–300 Ω. Stimulation is performed at high frequency (50 Hz), with pulse width of 1 msec, to induce paresthesias. Positive stimulation should occur at 0.1–0.3 V. A normal body temperature reading should be confirmed after insertion of electrode to confirm that the generator is working properly.

Straight (TIC) [48] and curved (TEW) [47] electrode kits are also available from Cosman®. The former were developed by Sweet and include different length exposed tips to adjust lesion size (2, 5, 7, and 10 mm). The TEW kit includes a straight and curved electrode. The latter allows for off-axis stimulation and lesion creation using the curved electrode. This may facilitate lesion creation in the maxillary division.

A cable is necessary to connect the electrode with the RF generator. The Cosman® CB112-TC cable is compatible with both types of electrodes [47, 48].

Fluoroscopy is essential for safe lesion generation. Radiation safety protocols must be followed. Radio-opaque gloves may offer some additional protection for the surgeon. The senior author notes that with experience, the amount of fluoroscopy needed for localization is drastically reduced.

Indications and Contraindications

The indication for this procedure is trigeminal neuralgia. The diagnosis of this disease is a clinical one. The decision to pursue percutaneous gangliolysis may depend on patient-specific factors, such as age and medical comorbidities, or disease-dependent factors, such as the presence or absence of NVC.

Medical comorbidities that significantly increase the risk of general anesthesia and surgery should be considered. Patient tolerance of risk should play a role in decision-making. Major complications such as stroke, infection, and CSF leak are rare for craniotomy but are nearly unheard of during percutaneous procedures. Hospitalization and recovery time must also be taken into account, as RF gangliolysis is an outpatient procedure that generally causes minimal discomfort and requires minimal recovery time, in contrast to craniotomy, which requires ICU care, hospitalization, and recovery over weeks. Finally, while age does not affect pain outcomes for MVD for TN [42], it is important to consider whether the additional risks and the burden of recovery from open surgery is worthwhile in patients whose life expectancy may not exceed a one or two half-lives of a less-invasive procedure such as RFL that may in most cases be repeated if necessary.

Disease-dependent factors that may indicate for a percutaneous approach rather than open surgery include the presence or absence of NVC and the diagnosis of multiple sclerosis (MS). When posterior fossa exploration for TN reveals no NVC, MVD is not possible; while ablative procedures such as PSR are often successful, they have proven less effective and durable than MVD [39, 53]. With the advent of high-resolution MRI combined with MR angiography, it is possible to ascertain whether a patient has NVC with a very high level of sensitivity and specificity [28, 33]. It is thus possible to counsel patients as to whether a posterior fossa exploration is likely to result in a MVD or a less effective procedure such as PSR.

Admittedly, a rigorous comparison of percutaneous procedures versus posterior fossa exploration has not been performed. The reported half-life of partial sensory rhizotomy via posterior fossa approach ranges widely, with 50 % recurrence rate reached from 2 to 5 years after surgery [6, 53]. A similar range in recurrence rates is reported for RFL but often includes retreatment [6, 22]. Thus, proceeding with RFL in the tic patient without NVC is a reasonable option.

The utility of MVD in the patient with MS has generated some controversy. Some advocate that patients with MS and NVC should be offered MVD, as nearly 50 % maintain pain-free results for more than 4 years [41]. Others report that 50 % of patients with MS undergoing MVD relapse in 3 months [1]. The largest series evaluating posterior fossa exploration for TN in patients with MS contained only 35 patients [5]. This series found no relationship between pain recurrence and the presence of NVC [5]. Importantly, comparison of varying treatments for TN in MS patients finds no significant difference in pain-free outcomes between MVD and RFL [34]. This same review advocates for MVD based on a lower complication rate for open surgery; however, hypoesthesia was considered a complication of RFL [34]. This is confusing, as some degree of hypoesthesia is generally a goal of the procedure. Given equal efficacy between MVD and RFL in the short and long term [34], the present authors advocate percutaneous approaches in MS patients as first-line treatment for TN.

Major contraindications to RFL of the trigeminal nerve relate by and large to the proper diagnosis of idiopathic trigeminal neuralgia.

It is important to confirm that the distribution of pain lies within the distribution of the trigeminal nerve. Nervus intermedius neuralgia presents with lancinating pain deep within the ear and would not be affected by ablation of the trigeminal nerve. Likewise, glossopharyngeal neuralgia, characterized by lancinating pain deep in the oropharynx, particularly with swallowing, should not be treated with a trigeminal nerve lesion. Both of these non-trigeminal tic pain syndromes are quite rare when compared to trigeminal distribution. The possibility of other specific syndromes associated with facial pain (e.g., Gradenigo, Raeder, Tolosa-Hunt) should be considered and addressed appropriately.

Facial pain syndromes that are not idiopathic trigeminal neuralgia should not be treated with ablative procedures. Examples of this include postherpetic pain, traumatic neuropathic pain, and trigeminal deafferentation pain. The first is usually characterized by a deep, constant, burning pain, often affects the first division in elderly patients, and is preceded by appearance of characteristic vesicles. The latter two are often the result of iatrogenic injury, whether it is directed at the trigeminal nerve intentionally, after ablative procedures for trigeminal neuralgia, or unintentionally, as seen after sinus surgery or dental procedures.

The rationale for ablative procedures in such cases is questionable, as onset of pain in these syndromes is related to damage to the nerve. It is unlikely that further damage with radiofrequency thermoablation, or any other technique, would be of benefit in such cases.

There are other contraindications to performing an RFL that are patient related. The patient must be able to communicate in order to participate in stimulation mapping. In some MS patients, verbal communication is not possible. In cases where the surgeon and patient do not share a common language, communication is also difficult. The use of an interpreter in the OR can be problematic; needle insertion has, in the experience of the senior author, caused dramatic vasovagal response in personnel unaccustomed to the OR, with predictable and unwelcome results.

Finally, the authors do not use RFL when trigeminal first division pain is being treated. Because the procedure results in hypoesthesia, the risk of corneal numbness, and subsequent keratitis, rises when treating V1. Balloon gangliolysis is our recommendation for these cases.

Technique

The operating room should be configured with the following in mind:

1. 1.

   The position of the surgeon should account for the side of the pain to be treated, the handedness of the surgeon, and the comfort of the surgeon in handling the needle with either hand. The senior author stands to the patient's right for all procedures, using the right hand to direct needle for left- or right-sided pain; alternately, the surgeon may find it easier to stand on the affected side, using either hand to guide the needle. In either case, the room should be arranged accordingly (Fig. 4.1).

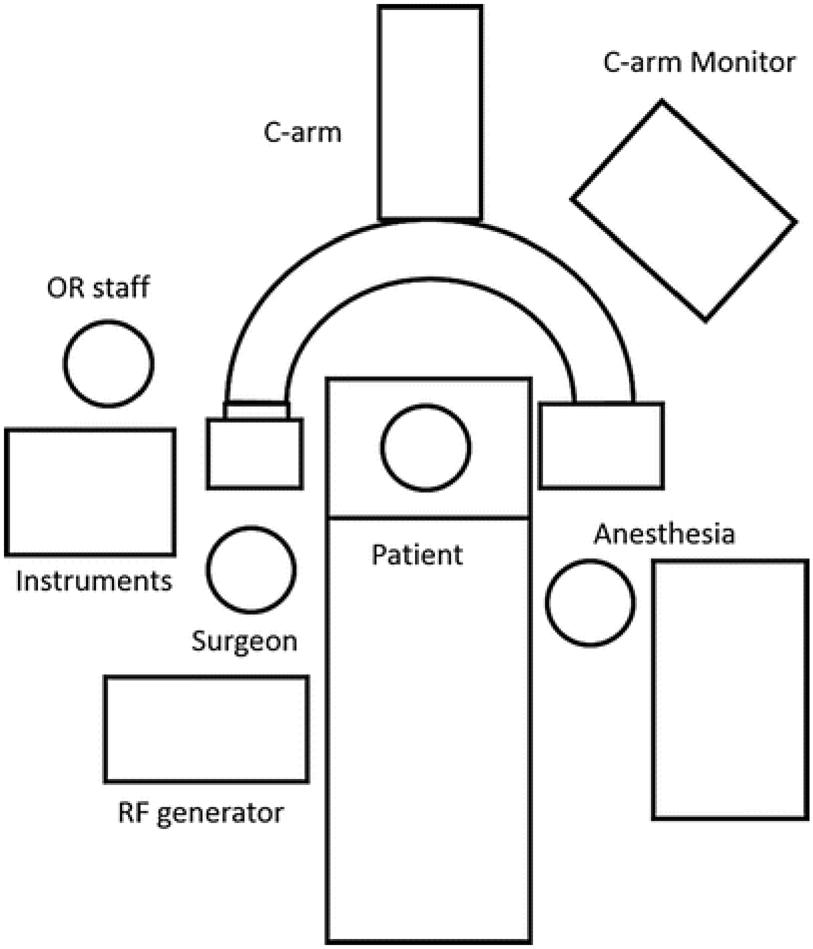

Fig. 4.1

Schematic for operating room during RFL procedure. This diagram represents a right-sided procedure for TN. The surgeon stands to the patient's right. Anesthesia is positioned contralaterally, with the anesthesia machine available for ventilation if needed, and IV access obtained on the left. The C-arm should be positioned so that an SMV and a lateral view are possible. The monitor should be easily visible to the surgeon. OR staff is shown on the patient's right, with enough proximity to hand instruments to the surgeon. The surgeon is able to reach and manipulate the RF generator while monitoring the patient during stimulation mapping and lesion creation

2. 2.

Anesthesia should have access to the airway to provide assistance with ventilation if needed. The IV should be placed in the arm nearest anesthesia to allow access during the procedure if necessary.

3. 3.

Fluoroscopy is essential for performing the procedure safely. The C-arm should be positioned prior to induction of anesthesia. The monitor should be easily visible to the surgeon. Radiation safety for operating room personnel must be considered.

4. 4.

Simultaneous access by the surgeon to the radiofrequency generator and the patient must be possible during stimulation mapping and lesion creation.

A useful schematic for the procedural setup is shown in Fig. 4.1.

The patient is positioned supine with the head in a neutral position. It is helpful to place the operating table in a "beach-chair" position, slightly elevated at the knees, flexed at the hip, with the neck extended. The arms should be secured to minimize movement during sedation and during the procedure. Glycopyrrolate, 0.2 mg, should be administered IV prior to the initiation of the procedure to ameliorate the effects of the trigemino-cardiac reflex, which can be severe enough to induce asystole. With this precaution, we have not found it necessary to place transcutaneous pacer electrodes as others advocate. Transient tachycardia is the most troubling side effect. Additionally, no premedication with benzodiazepines should be given, to allow for faster awakening and more accurate testing.

Fluoroscopy is used to obtain a submentovertex view (SMV) of the base of the skull. The foramen ovale can thus be visualized, which is helpful for needle placement within the ganglion (Fig. 4.2). The senior author notes that, with experience, this view is unnecessary. In this case, a straight lateral view should be obtained, with care taken to align both auditory canals and the planum sphenoidale oriented perpendicular to the floor.

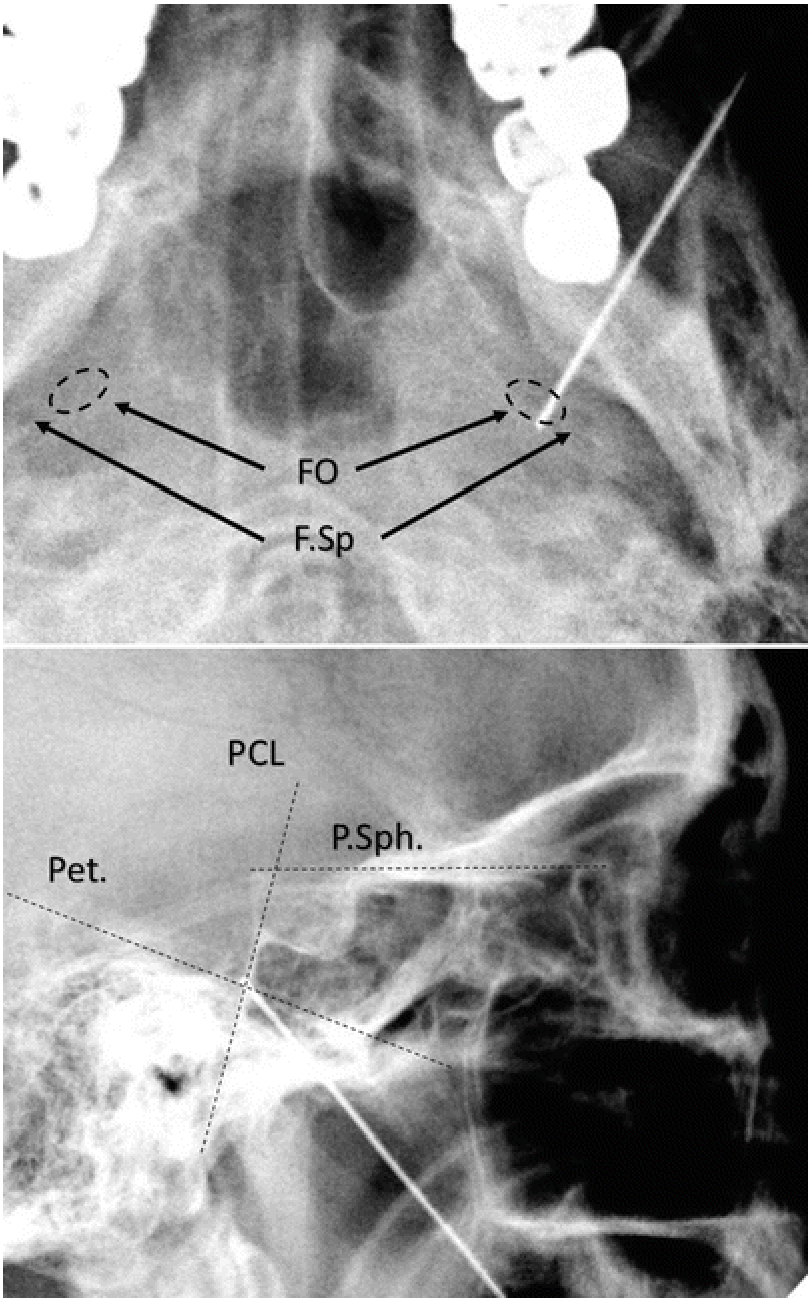

Fig. 4.2

Submentovertex (SMV) and lateral view of RF needle within foramen ovale (*FO*). *Top*, SMV view of the skull base with RF needle in FO. Note that the foramen spinosum (*F.Sp.*) is often easier to see than the FO itself. The FO will be anterior and medial to F.Sp. As seen here, the contralateral side can also be useful in localizing the needle. *Bottom*, lateral view of the skull base. This view should be as true as possible, which can be confirmed by aligning the auditory canal. The needle is directed at a 45° angle to the planum sphenoidale (*P.Sph.*), directed at the intersection between the petrous ridge (*Pet.*) and the posterior clival line (*PCL*). The electrode pictured is positioned with the tip at the PCL. In this patient, stimulation at 50 Hz with the electrode in this position produced parasthesias in V2

Preoxegenation for 3–5 min on 100 % oxygen with anesthesia mask is initiated, followed by conscious sedation with Propofol®. Ideally, the patient should be in Plane I of Stage III anesthesia for the placement of the radiofrequency needle. A variety of agents have been used in the past, with varying degrees of success. At a minimum, the choice of anesthesia must control the pain induced by introduction of the radiofrequency needle, and it must be short-acting, to allow for stimulation mapping and evaluation of the lesion created. In our experience, a bolus dose of 40 mg of Propofol®, repeated once per minute, is most effective for achieving the necessary sedation, while allowing the patient to awaken in a timely fashion.

A nasopharyngeal airway may be placed for ventilation if needed. During the procedure, jaw thrust may be needed to maintain the airway. Ventilation via the nasopharyngeal airway, or even mask ventilation, may be needed if the patient becomes apneic or hypoxic. Esmolol or nicardipine boluses may be used to control hypertension. We usually suggest that the systolic blood pressure be maintained below 160 mmHg.

The patient's cheek should be prepared with an antiseptic solution. With TN, it is more humane to wait until the patient is anesthetized before this step. Betadine has the advantages of being visible on the skin and can be used near mucus membranes. The patient's chest and neck should be draped with sterile towels, but the patient's face should remain exposed. This allows identification of anatomic landmarks and assessment of sensation once the lesion is created.

There are three anatomic landmarks important for needle placement:

1. 1.

   A coronal plane 3 cm anterior to the external auditory meatus

2. 2.

   A sagittal plane at the mid-pupillary line

3. 3.

   A point 2.5 cm lateral to the labial commissure in the mid-occlusal plane

The first two landmarks define the location of the foramen ovale; the third represents the site of needle insertion.

A nick is made in the skin, 2.5 cm lateral to the labial commissure, in the mid-occlusal plane. A finger may be introduced into the mouth to help prevent introducing the radiofrequency needle through the buccal mucosa and into the oral cavity. If doing so, the finger should be removed once the needle is past the coronoid process of the mandible, and gloves should be exchanged. The cannula with stylet inserted should be directed toward the ipsilateral pupil and toward a point 3 cm anterior to the external auditory meatus. The intraoral finger technique is not necessary once one has experience with this operation.

If using an SMV view, this trajectory will often direct the needle onto the greater wing of the sphenoid, anterior to the foramen ovale. Once the skull base is reached, the cannula can be redirected using fluoroscopic guidance, which will provide orientation in the lateral and anterior-posterior directions. With the needle in view, the foramen ovale may be obscured or difficult to visualize. The ipsilateral foramen spinosum may be a useful landmark in this case, with the foramen ovale located anteromedially; the configuration of the contralateral side may also be useful for localizing the target (Fig. 4.2).

The needle will "pop" into the foramen ovale; entering the ganglion is often accompanied by a jaw-jerk produced by a brief contraction of the masseter muscle. The C-arm should then be directed into a straight lateral view as described above. With experience, it is feasible to use this view during the entire procedure and avoid moving the C-arm. The needle trajectory should be at 45° to the planum sphenoidale. The needle should be advanced toward the intersection of the posterior margin of the clivus (clival line) and the petrous ridge (Fig. 4.2).

The stylet is withdrawn and replaced with the RF electrode. CSF is often seen when the stylet is withdrawn. However, this may not be noted when performing a repeat procedure. The electrode should read body temperature. This is important to confirm that the RF generator is functioning properly. Impedance within the ganglion is 150–350 Ω. This is helpful to confirm that the needle is within neural tissue rather than CSF.

Advancing the needle past the clival line, within 5 mm, results in more contact with V1; contact with V3 is facilitated by keeping the needle slightly anterior to the clival line. A curved Tew electrode can facilitate contact with the second division, by directing the tip of the electrode medially or cephalad, at the level of the clival line.

Once the electrode is in the desired position, the patient is allowed to awaken. Stimulation at 50 Hz produces paresthesias. This is usually noted with stimulation amplitude between 0.1 and 0.3 V. Stimulation at low frequency (2 Hz) should not elicit motor activity at less than 0.5 V. If motor activity is noted at lower voltage, the needle is likely within V1 fibers and too close to the motor fibers. If paresthesias are not noted in the affected division, the electrode should be repositioned.

To do so, it is useful to remember that the preganglionic fibers of CN V are arranged with V1 fibers superomedially, while V3 lies more laterally and inferiorly. As a general rule, advancing the electrode along the axis of the foramen ovale will move stimulation from

V3 toward V2 and then V1. The use of a curved electrode directed medially and cranially has a similar effect. For example, if a straight electrode located at the clival line stimulates V2, and a lesion is desired in V3, the curved electrode can be introduced pointing laterally and caudally to reach these fibers. Alternately, if the electrode is withdrawn a few millimeters, the straight electrode is likely to be within V3 as well.

When electrode localization is confirmed, the patient is re-anesthetized for lesion creation, as this can be quite uncomfortable. Raising the temperature very slowly can ameliorate the patient response to this process. An initial lesion is made at 70° for 90 s. The patient is then reawakened, and sensation is tested. The goal is to create a lesion where the patient cannot distinguish pinprick from dull sensation in the affected division. This demonstrates selective lesioning of A-delta and C-fibers that carry sensation of pain and temperature. Additional lesions can be created as needed, using higher temperatures if necessary. This is often the case for repeat procedures. Creating the minimum lesion necessary to abolish pain lessens the incidence of dysesthesias after this procedure.

Once lesion creation is completed, the cannula and electrode are withdrawn without administration of further anesthesia. A small dressing may be placed. The patient is recovered in a postanesthesia care unit and discharged home. Patients may require some analgesic medications for tenderness in the face after this procedure. A typical procedure takes about 45 min of operating room time, and the patient goes home after an hour or two in recovery. If the desired sensory loss and pain relief have occurred, the patient should taper his/her oral tic medications by one less pill of each medicine per day.

Complications

Complications of this procedure can occur intraoperatively or may represent sequelae from the lesioning itself.

There are several structures to avoid during cannulation of the foramen ovale. The superior orbital fissure is anterior and superior to the foramen ovale. The jugular foramen lies posteriorly and inferiorly. The foramen of Vesalius lies anteromedially. The canal of Arnold, containing the lesser petrosal nerve, is located posterior to the foramen ovale. Advancing the needle into these structures results in piercing the temporal lobe. Attention to anatomic landmarks and use of fluoroscopy during needle manipulation are important in avoiding these structures. On a lateral x-ray, the proper trajectory should be at a 45° angle to the planum sphenoidale. The needle tip should be directed at the intersection of the petrous ridge and the posterior clivus. If the needle is directed at the sella turcica or anterior to the sella, it is too anterior; this is particularly important, as stimulation at these sites has been known to cause paresthesias in V2, in which case stimulation mapping provides an inaccurate assessment of localization [45].

The internal carotid artery is at risk at three sites: at the foramen lacerum (posterior and medial to the foramen ovale); within Meckel’s cave, at the petrous bone (posterior and lateral); or within the cavernous sinus (anterior and medial to the ganglion). If the carotid is penetrated (a very rare event), the needle should be withdrawn immediately and repositioned. Once within the foramen, the needle should not be advanced more than 5 mm past the clival line, as this may result in damage to CN VI. The incidence of diplopia from injury to this nerve, or to CN III and IV, is about 1 % [45].

Some degree of hypoesthesia within the treated distribution is expected with RFL in nearly all patients and should not be considered a complication [6, 22, 45, 46]. The presence of unpleasant or painful dysesthesias, however, is much less common. The incidence of dysesthesias has been seen in as much as 15–20 % of patients [6, 45] but are considered bothersome or major (anesthesia dolorosa) in 0.5–4 % of patients [6, 8, 22, 45, 46]. The overall incidence of keratitis is rare and reported in less than 2 % of patients [6, 45, 46], though the rates of corneal numbness can be as high as 20 % [8]. It is important to note that innervation of the inferior cornea is often by V2, so patients with pain treated in this distribution should be warned regarding the possibility of corneal abrasion. Of note, most large studies report that the incidence of these complications has dropped as larger, more complete sensory lesions have been abandoned for more precise lesions [6, 22, 46].

Temporary masseter weakness can be seen in a sizeable proportion of patients (15 %) but is nearly always temporary, resolving within 6 months [8, 45, 46]. Infection, intraparenchymal hemorrhage, stroke, and death have been reported, but are extremely rare, with a handful of cases reported in several thousand cases [45, 46].

Outcomes Data

All treatments for TN have a half-life. It is important to bear this in mind when discussing treatment modalities with TN patients. No large, comprehensive, randomized-controlled trials comparing treatments for TN have been performed, and as of 2011, there is no Class I evidence for the efficacy of even the most widely accepted surgical treatments for TN [56]. Nevertheless, several salient points can be made regarding treatment effectiveness and durability when considering the options for treating TN.

It is extremely important to bear in mind what is considered successful treatment. We define success as a patient who is pain-free on no medications for tic. For most surgical procedures, including MVD, PSR, and RFL, success is defined similarly. However, most reports on the efficacy of SRS do not use these criteria for success, which can result in some confusion when considering results for gamma knife procedures. The Barrow Neurological Institute Pain Scale (BNI-PS) is a widely used outcome scale for facial pain. In its simplest form, this score is determined as follows:

BNI-PS Grade:

- I: No trigeminal pain; no medication

- II: Occasional pain, not requiring medication

- III: Some pain, adequately controlled with medication
- IV: Some pain, no adequately controlled with medication
- V: Severe pain, no relief

This scale was initially introduced to grade outcomes from SRS. It is imperative to bear in mind that for outcomes for RFL, only BNI-PS Grade I patients are considered treatment successes. For many SRS studies, Grades I–III are treatment "successes" [25, 32]. Thus, SRS outcomes must be considered in light of these differing criteria for success.

Initial rates for pain-free outcomes using RFL are quite good. Complete pain relief has been reported as high as 97.6 % [22]. Median time to recurrence may be as short as 24 months [49, 55]. Our experience, as reported by Burchiel et al. in 1981, shows a median time to recurrence of about 3 years; allowing for repeat procedures, the rate of pain-free outcomes at 6 years is 78 % [6]. The upper range of treatment durability is seen in two large studies, by Kanpolat and van Loveren of about 1500 and 700 patients, respectively, reporting about 60 % of patients remaining pain-free at 5 years [22, 50]. At 5 years, recurrence has been reported as high as 65 % [6] and as low as 39 % [50]. The durability of this treatment is affected by the density of hypoesthesia achieved during treatment, with large, dense lesions leading to a lower rate of recurrence, at the expense of a higher rate of sensory dysfunction and dysesthesias [46]. This may explain the large variation in reported outcomes [8, 49]. Pain recurrence can be retreated with RFL with similar effectiveness [22], with the same caveats. Importantly, the presence of dense hypoesthesias in the same distribution of pain may indicate that a repeat lesioning will not be effective.

Microvascular decompression has long been considered the gold standard for treatment of TN when NVC is present, with several large observational studies supporting its safety and efficacy [2, 6, 43]. However, when MVD is not possible because of the lack of NVC, or when medical comorbidities increase surgical risk unacceptably, other modalities of treatment must be considered. In comparison to percutaneous procedures or SRS, the invasive nature of MVD must also be taken into account when counseling patients of more advanced age, in whom less durable but effective percutaneous procedures may provide quality results at less risk, with less recovery time.

The three widely practiced percutaneous treatments for TN are comparable in outcomes. Glycerol rhizolysis and RFL share similar pain-free outcomes that are often related to the degree of hypoesthesias obtained during treatment [8]. Balloon compression may have lower rates of post-procedural dysesthesias and is preferred by the authors when V1 distribution pain is present but tends to have slightly higher rates of recurrence [8]. Each of these procedures has significantly less recovery time than MVD.

Long-term pain control (not abolition of pain, BNI-PS Grade I–III) is achieved with SRS in 50–75 % of patients at 5 years [25, 32]. While this seems comparable to results of other ablative procedures, one must bear in mind several caveats regarding radiosurgery. Pain relief may be delayed by weeks, and criteria for successful treatment are much less stringent, as improvement in symptoms while on medications is a successful SRS result, in contrast to percutaneous procedures which aim for immediate abolition of symptoms without the need for medications.

In discussions with patients, the authors summarize these results as follows: 90 % of patients get immediate pain relief with MVD, and 50 % of patients undergoing MVD in the context of NVC are pain-free at 10 years; without NVC, the rate of being pain-free is about 50 % at 5 years; treatment with RFL has similar results in the short term, with 90 % of patients experiencing immediate pain relief, but the average half-life of treatment is 3 years; importantly, the rate of pain-free outcomes with repeated treatment is about 80 % at 6 years. SRS provides 70–80 % of patients with some relief of their symptoms, and 50 % of patients maintain improved symptoms at 5 years, but the chance of being off all medications is significantly lower, with only 30 % of patients having a Grade I outcome [25].

Conclusion

RFL is an effective treatment for TN. Major complication rates are low. The most likely complications are related to the extent and density of lesion created and has been mitigated by the treatment strategy of minimizing the amount of hypoesthesia created during thermoablation.

While acutely effective, RFL has a treatment half-life of about 3 years. However, the lesion can be repeated several times. Allowing for multiple procedures, pain-free results for TN treated with RFL can be as high as 80 % over 6 years. Given that this is a minimally invasive, well-tolerated outpatient procedure with low risk of complication, this is a very reasonable option for the management of TN.

Examination of practice patterns in the USA show that the rate of MVD for TN has remained relatively steady from 1988 to 2010 at over 2000 cases per year, while the number of percutaneous procedures has dropped from about 1500 cases a year to 250 cases a year [40]. It is difficult to say what has driven this change. There has not been a significant change in reported outcomes for percutaneous procedures during that time. This decrease in percutaneous procedures is not due to an increased use of SRS [40]. One possible interpretation is that there has been a decrease in the number of practitioners the expertise necessary to perform these procedures.

Given that RFL is a safe and effective treatment for TN, it is important that the surgeon or physician treating facial pain maintains the ability to offer this treatment.

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