J Neurosurg 121:1497–1503, 2014

Use of sensory and motor action potentials to identify the position of trigeminal nerve divisions for radiofrequency thermocoagulation

Clinical article

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Object. The objective of this study was to develop an electrophysiological method for intraoperative localization of the trigeminal nerve branches during radiofrequency thermocoagulation (RFTC).

Methods. Twenty-three patients who were scheduled to undergo RFTC were included. The trigeminal nerve root was stimulated through the foramen ovale using the radiofrequency cannula. Antidromic responses were recorded from the target division through supraorbital, infraorbital, and mental foramina electrodes, and an additional electrode at the masseter muscle. Sensory and motor action responses, as well as verbal and masseter contraction responses, were recorded and correlated.

Results. The antidromic responses were easily recorded in the target division in all 23 patients, and they were invariably correlated with the patient's verbal responses. The potentials were recorded successively from V1 to V3. The amplitude in each division before and after RFTC showed little difference in response to electrical stimulation with the same current. The motor trigeminal nerve action potentials were recorded in 10 patients; 7 of these patients had postoperative masseter muscle weakness, while the remaining 3 had normal masseter muscle function. Potentials with low amplitudes were usually obtained from neighboring divisions, but no unexpected denervation of any branches was observed. All the patients experienced immediate pain relief after the procedure.

Conclusions. This technique is sensitive and easy to apply. The sensory and motor potentials matched the verbal responses and the complications. Although it cannot completely substitute for the patient's verbal response, this approach is helpful in uncooperative patients, and it predicts and reduces the incidence of masseter muscle weakness. The use of these complementary techniques could increase the chances of treatment success.
(http://thejns.org/doi/abs/10.3171/2014.8.JNS132484)

Key Words • **trigeminal neuralgia** • **electromyography** • **sensory response** • **functional neurosurgery** • **pain**

Trigeminal neuralgia is one of the most severe facial pain syndromes. Pharmacological management is the initial treatment option for trigeminal neuralgia. However, some patients do not respond to drug treatment and others have refractory symptoms even after treatment. Several reported studies have demonstrated the effectiveness of percutaneous radiofrequency thermocoagulation (RFTC) in the treatment of trigeminal neuralgia in patients who have refractory symptoms despite maximal pharmacological treatment.[10,12,13,17,19,21] The principle of the RFTC technique remains unresolved. Previous research has demonstrated that the temperature-dependent selective destruction of small, unmyelinated pain fibers can be achieved,[7,15] which allows the surgeon to make a controlled, selective lesion in the ganglion. Smith et al. studied such radiofrequency lesions in the nerves of dogs and using histological techniques they observed the nonselective destruction of all fibers after thermocoagulation.[20] The correct positioning of the electrodes is important in RFTC, as placing the electrode in the wrong position can lead to meningitis, abscess formation, carotid-cavernous fistulas, or even brainstem injury.[3,18]

The location of paresthesia induced by low-voltage stimulation provides an accurate guide to the position of the electrode in the rootlets or ganglion during surgery.

Abbreviations used in this paper: EMG = electromyography; MTAP = motor trigeminal action potential; RFTC = radiofrequency thermocoagulation; STAP = sensory trigeminal action potential.

This article contains some figures that are displayed in color online but in black-and-white in the print edition.

At present, surgeons depend on the patient's response to such stimulation to identify the correct division within the nerve root and to assess the effect of surgical lesions. The evaluation of a patient's verbal responses to square-wave stimulation of the trigeminal ganglion is the main method to ensure that the electrode/cannula is in the correct position.[16] However, patients experience some degree of discomfort and stress in this procedure, and this method also depends on factors such as emotional stress, language comprehension, and expression. These factors may lead to insufficient or confused verbal responses followed by imprecise lesion localization or even therapeutic failure.[2] Moreover, because the cooperation of patients is essential to this procedure, continuous general anesthesia is not recommended, and therefore discomfort and stress associated with the procedure may increase.

In an effort to improve accuracy, previous studies have been performed to investigate the application of orthodromically elicited potentials of the trigeminal nerve,[2,5,12,14] which were helpful for electrode localization during surgery. However, the results were contradictory and tedious applications were needed.[6,8–10] There is a little evidence in the published literature on antidromically elicited potentials[1] to show that their use is an alternative and complementary approach that can improve the accuracy of electrode positioning in RFTC.

In this study, we investigated an electrophysiological method, complementary to but independent of the verbal response method, which can be used to identify the divisions of the trigeminal nerve and therefore the position of the electrodes in RFTC. The principle of the technique is the identification of the relevant branches of the trigeminal nerve by antidromic potentials. With this technique, the surgeon can precisely locate the electrode tip and predict the complication of masseter muscle weakness.

Methods

Patient Population

The study was conducted in 23 patients who had been treated previously with carbamazepine but were intolerant to this medication or had developed refractory symptoms. An MRI examination was performed to confirm the presence of nonneoplastic facial pain. In all patients, trigeminal nerve function was assessed a few days before surgery by means of a sensory function test. Idiopathic trigeminal neuralgia was diagnosed and patients were scheduled to undergo percutaneous RFTC treatment of the ganglion and root.

Localization of the Electrodes

Propofol, a short-acting anesthetic agent, was used to induce general anesthesia. An 18-gauge, 10-cm radiofrequency cannula with a 5-mm active tip (RFG-1A Generator, Cosman) was used for cannulation. After administration of 1% lidocaine, the cannula was advanced in a straight line toward the foramen ovale as previously reported,[10,11,16] under the guidance of a neuronavigator. When the cannula entered the foramen ovale, masseter muscle contraction was observed, and a CT scan was obtained to ensure that the tip had passed through the foramen ovale. Following this, the electrode was advanced 6–9 mm further to reach the preganglionic fibers of the Gasserian ganglion. The stylet was then removed from the cannula to check that there was no vascular damage and the CSF was clear.

The patient was then awakened. The precise localization of the tip was confirmed using electrostimulation with square-wave pulses at 0.1–0.2 mA (50 Hz, 0.2 msec).

Sensory trigeminal action potentials (STAPs) from the first, second, and third divisions were serially recorded using the Keypoint neuromonitor (Alpine Biomed): a fine needle electrode was inserted subdermally near the supraorbital, infraorbital, and mental foramina, and the reference electrode was placed 10 mm away. Direct motor responses were recorded by additional needle electrodes inserted into the masseter muscles. Central stimulation of the trigeminal nerve by the tip generated a retrograde conduction, which could easily be observed by the peripheral recording of the 3 trigeminal nerve divisions (V1, V2, and V3). Motor trigeminal action potentials (MTAPs) were elicited by stimulation of the Gasserian ganglion and rootlets, usually when the third division was involved. The direction of the cannula was adjusted when motor responses or responses from the wrong divisions were produced. Signals were recorded from the screen, and the maximum peak-to-peak amplitudes were measured (Fig. 1).

At the threshold, the sensation was not painful and could therefore be located and described calmly by the patient. Sensory and motor potentials elicited by square waves, as well as verbal and masseter contraction responses, were recorded and correlated.

RFTC Treatment

Once the branch or branches to be treated were confirmed, 0.1 ml of 0.25% lidocaine was injected to induce

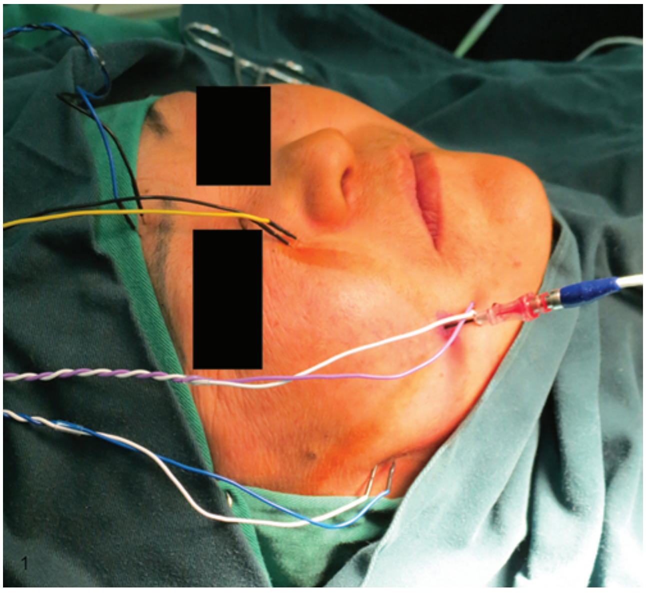

Fig. 1. The needle electrodes were inserted near the supraorbital, infraorbital, and mental foramina for sensory recordings; additional electrodes were inserted into the masseter muscle for motor recordings.

anesthesia. Then, RFTC was initiated, with the temperature monitored at 60°C for 1 minute; thermocoagulation was repeated until analgesia developed in the involved branch, usually 3 times. Sensory deficit was evaluated with the pinprick and 2-point discrimination tests and corneal reflex examination before the temperature was increased. The surgeon then gradually increased the temperature in 10°C increments, with the induction of a lesion at each temperature stage. The maximum temperature was 80°C. Sensory and motor potentials were recorded during the lesion inductions. The procedure was completed when adequate hypalgesia was achieved in the target branch and pain could not be triggered as it had been preoperatively. STAPs and MTAPs were recorded again by square-wave stimulation and compared with those recorded before the thermocoagulation. Finally, the radiofrequency cannula and recording needles were removed and the patient was kept under observation for 6 hours. The patients were required to undergo a physical examination of the trigeminal nerve divisions before discharge.

Results

Patient Characteristics

The patient group included 18 women and 5 men, ranging in age from 44 to 77 years (average 62.0 years). Of the 23 patients, 21 suffered from the involvement of the third branch alone or in combination with the second division. The remaining 2 patients suffered from the involvement of the V1 or V2 branch alone, respectively (Table 1).

Potentials Elicited by Square-Wave Stimulation

In response to square-wave stimulation, STAPs were obtained from each trigeminal nerve division in all patients, and the amplitudes ranged from 0.1 to 1.0 mV. The potentials were recorded from V1 to V3 successively. The interval between each signal recorded after the square-wave stimulation remained stable at 20 msec in all of the branches, in accordance with the frequency of electrical stimulation (50 Hz, 20 msec; Fig. 2).

Once the lesions were induced, electromyography (EMG) findings showed that the targeted division had stationary signals, while the other divisions had sharply fluctuating signals (Fig. 3). Moreover, there were no significant differences in the amplitudes and shapes of waves in response to electrical stimulation before and after thermocoagulation.

The STAPs were invariably correlated with verbal responses with regard to the sequence of the divisions, and no denervation in any unexpected divisions was noted in any of the cases. However, on some occasions, lower amplitude potentials were obtained from the neighboring division (Figs. 2 and 4).

In 5 cases, the V1 recording was contaminated by waves from the orbicularis oculi, as stimulation above the threshold of tactile perception caused pain and the patient frowned subconsciously. However, the myogenic artifacts could easily be distinguished from the STAPs by their irregular pattern (Fig. 4).

MTAPs were usually recorded in the distal anterolateral portion of the third division and were correlated closely with visible clinical motor responses and with verbal responses that most frequently reflected muscle contraction. The amplitude of the M-waves depended on the exact positioning of the tip of the electrode within a lower or upper division of the nerve root. Correlations between the clinical findings and neurophysiological data are shown in Table 2.

TABLE 1: Demographic and clinical characteristics of the patients

Variable	Value (%)
sex	
male	5 (21.7)
female	18 (78.3)
previous RFTC	
none	16 (69.6)
more than once	7 (30.4)
affected divisions	
V1	1 (4.4)
V2	1 (4.4)
V3	12 (52.0)
V2 & V3	9 (39.1)
prior surgical treatment	
local blocks	2 (8.7)
RFTC	8 (34.8)
Gamma Knife	1 (4.4)

Treatment Prognosis and Complications

All patients experienced immediate relief of symptoms after surgery, and medical treatment was therefore discontinued. No cases of postoperative keratitis occurred, and transient minor masseter weakness with chewing occurred in 8 patients. However, no cases with permanent weakness of the masseter muscles were observed. The EMG findings were in agreement with the clinical effects in cases with only V1 or V2 involvement. However, in the 11 cases with V3 involvement, 6 had unexpected MTAPs, which were associated with transient masseter weakness in 4 cases. The sensitivity and specificity were 80% and 66.7%, respectively (Table 3). Among 10 patients with V2 and V3 involvement, 4 had undesired MTAPs, 3 of whom developed transient masseter weakness. The MTEP signals were recorded in 7 of the 8 patients with transient masseter weakness. Moreover, in 15 patients with normal postoperative masseter function, 3 showed motor branch signals. The sensitivity and specificity were 100% and 85.7%, respectively (Table 3).

Discussion

RFTC is widely used to treat trigeminal neuralgia. Previous research led to the development of additional refinements to minimize unwanted side effects and improve the efficacy of this technique, including electrophysi-

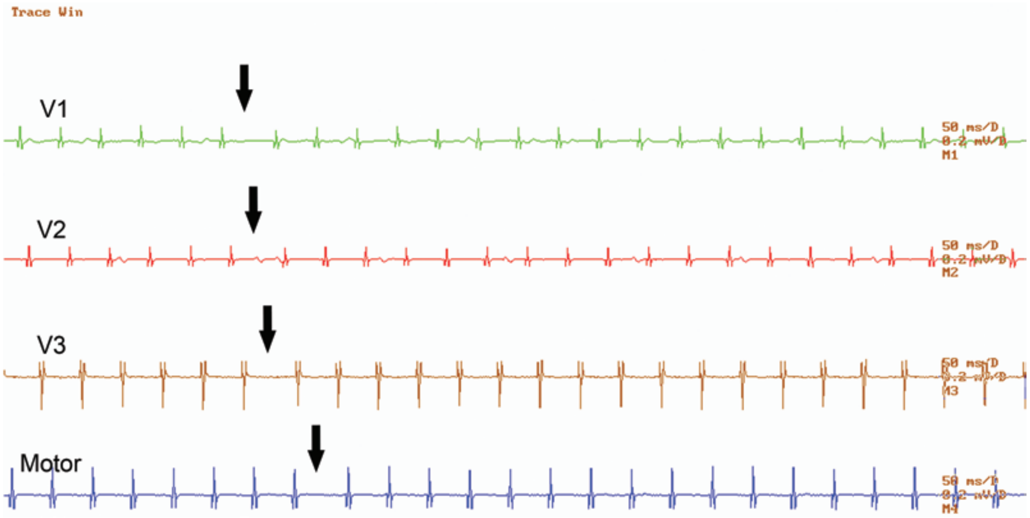

Fig. 2. Graph showing electrical stimulation of the trigeminal nerve in 1 patient. Lines 1 to 4 represent V1, V2, V3, and the motor branch, respectively. The tips were maintained at specific positions so that all the branches could be evoked. The recording signals did not appear simultaneously, but successively in the order of V1, V2, V3, and the motor branch. The *arrows* show the absence of 1 stimulation, which was used as the reference point to distinguish the order of V1, V2, V3, and the motor branch. The interval between each potential from the 3 branches was maintained throughout the stimulation period.

ological approaches. During surgery, nerve fibers are electrically stimulated by alternating currents or radiofrequency waves to generate action potentials. When the elicited action potentials transmit in the same direction as the physiological conduction, they are orthodromic. If the potentials are propagated in the opposite direction, they are antidromic. Bendersky et al.[1] reported the use of a helpful technique for electrode localization by analyzing the antidromic potentials in intubated patients under anesthesia. This method proved to be effective and comfortable for the patient. In the present study, a similar technique for evaluating antidromic sensory action potentials was used and some interesting manifestations were observed.

The only method for localizing the radiofrequency electrode to the target division is the verbal response of the patient. The wake-up procedure of the surgery usually causes discomfort. Factors such as emotional stress, language comprehension, and expression may lead to insufficient verbal responses, lack of cooperation, or even cardiovascular complications. In this study, we established an objective approach to evaluate the localization of the electrode tip. The technique is easy to apply, and no special equipment is needed except for the RFTC generator and standard EMG equipment used for sensory nerve conduction studies. The recorded STAPs correlated consistently with the verbal responses of the patients, and therefore the surgeon did not have to rely completely on the subjective

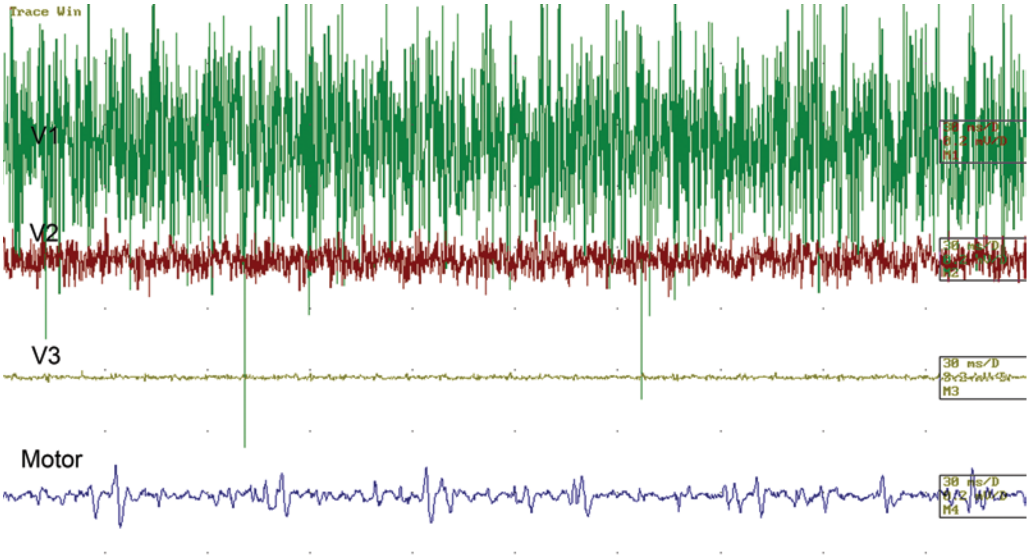

Fig. 3. Graph showing that when RFTC was performed, the target division (V3) remained stationary, while the signals from the other divisions (V1, V2, and motor) fluctuated sharply.

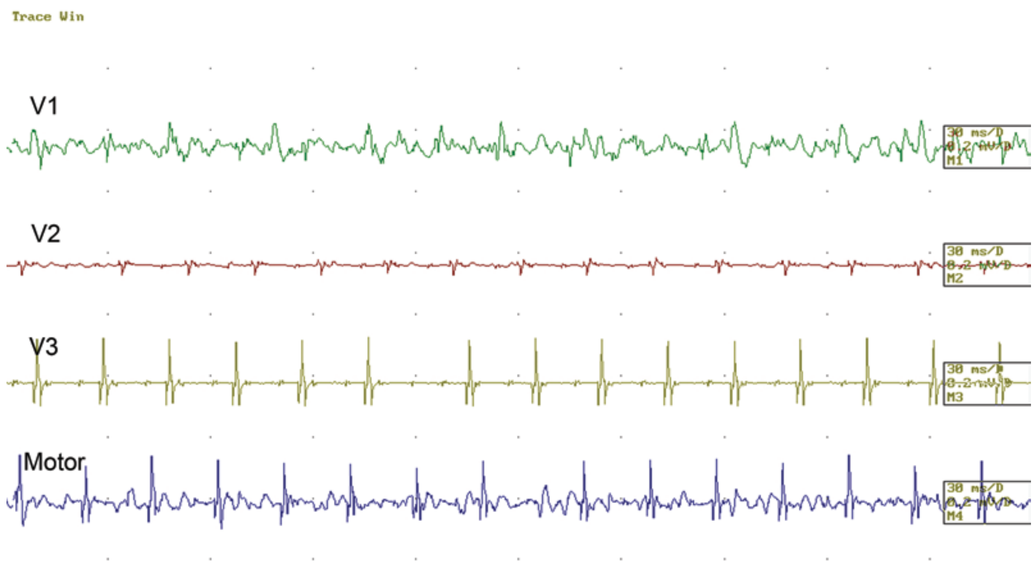

Fig. 4. Graph demonstrating that when the electrical stimulation (50 Hz, 20 msec) was continuously delivered, regular signals were recorded from V3 with an amplitude of 0.2 mV, usually accompanied by motor branch contraction, whereas the signal amplitudes from V2 were nonsignificant. The V1 division was contaminated by irregular wave forms, which were easily distinguishable.

assessment of the patient regarding numbness. In addition, the instantaneously recorded signals occurred earlier than the responses of the patient, which facilitated the early detection of an incorrect position. Furthermore, compared with the confused verbal responses by uncooperative or demented patients, this method may provide the surgeon with objective and reliable feedback regarding the operative strategy. This technique could therefore be combined with the verbal response technique to increase the chances of successful treatment. The RFTC requires the surgeon to have suitable experience, but the use of the objective indicator might enable inexperienced doctors to benefit from its guidance.

STAPs induced via stimulation through the foramen ovale correspond to the position of the electrode tip, and the tip of the cannula can be adjusted to the location with strong STAPs and no MTAPs. Theoretically, this would reduce the chances of masseter weakness, but because the sensory and motor branches are located close by,[24] the signals are usually concurrent. Temporary masseter weakness was noted in 34.8% (8/23) of the patients in this study; this incidence is higher than the incidence reported in a large series of patients.[4,11,13,21–23] The higher incidence in the present study may be attributable to the difficulty in microadjustment with the 18-gauge cannula. To obtain focal recordings from subdivisions, a small electrode tip is required, but the conventional 22-gauge cannula with a smaller tip does not meet the requirements of a navigator, as it is easily deformed during penetration; we therefore used the 18-gauge cannula. In the future, a rigid electrode with a small tip might be introduced to reduce this complication.

It was possible to predict masseter weakness based on the presence of MTAPs in 8 of the 10 cases during surgery. However, in 3 cases with MTAPs in the third division, no trigeminal motor complications occurred. All of the patients with masseter weakness recovered within 3 to 6 months. Therefore, although the technique itself did not reduce the incidence of temporary masseter weakness, this complication was predictable with our technique.

We cannot explain the occurrence of V1 artifacts in our research. These probably originated from the subconscious frowns of patients in response to pain during low-voltage stimulation in other divisions, but further investigation is needed to understand these occurrences.

The limitation of this technique is that patients have

TABLE 2: Correlations between the clinical findings and neurophysiological data

Location	Verbal Response	Masseter Weakness	Correlation*
V1	1	0	1
V2	1	0	1
V3	11	5	8
V2 & V3	10	3	9

* Cases of STAPs and MTAPs completely correlating with verbal response and complications (masseter weakness).

TABLE 3: Correlation between complications and MTAPs

Division	Masseter Weakness	Normal Masseter Function
V3*		
MTAPs	4	2
no MTAPs	1	4
V2 & V3†		
MTAPs	3	1
no MTAPs	0	6

* V3: sensitivity = 80% (4/[4+1]), specificity = 66.7% (4/[4+2]).
† V2 & V3: sensitivity = 100% (3/[3+0]), specificity = 85.7% (6/[6+1]).

to undergo the insertion of a needle, which is invasive. Furthermore, additional time was required when there was a need to make microadjustments to the electrode according to the STAPs and MTAPs. RFTC has been used for decades and its level of precision is relatively stable. The technique cannot significantly increase the precision of surgery compared with that obtained with other techniques.[10,11] Finally, because the STAPs showed little change before and after the lesions were made, we cannot as yet evaluate the curative effect of this technical modification. However, we believe that because this technique provides a further objective approach to evaluate the electrodes, it is worth the minimal invasion and limited amounts of additional time required. Further studies will be needed to improve the precision.

A total of 0.1 ml of 0.25% lidocaine was used before induction of the lesions. With such a low concentration and small dosage of medication, the patient was pain free without the loss of any detectable tactile sensation, enhancing the surgical strategy, and the range of diffusion could be limited in the expected division. That may explain the observation that the signals from the target division remained stationary when RFTC was performed, as the sodium channels were blocked. The communications between each branch may be responsible for the extreme fluctuations of the signals of other divisions. The effect of lidocaine did not last for a prolonged period, because it was eliminated after the lesions were created. Therefore, potentials could still be evoked after the lesion procedure.

The distance or conduction velocity of each branch cannot be computed with the present technique. In addition, the precise distance between the ganglion and cutaneous branches could not be calculated for individual branches, and because the stimulation cannula and record electrodes were from different devices, the latency could not be recorded either. Therefore, the conduction velocity could not be computed indirectly. Cruccu et al.[6] measured conduction distance on lateral radiographs and reported the average distance for the supraorbital, infraorbital, and mental foramina to be to be 81 mm, 79 mm, and 119 mm, respectively. However, the straight-line distance does not reflect the precise course of the nerve.

The sequence of signals recorded from V1 to V3 successively may be attributable to both differences in conductive distances[8] and the effect of lidocaine. We therefore believe that STAPs are more accurate than conduction velocity.

Another observation of this study was that after thermocoagulation, the amplitude of STAPs in the target branch did not show a significant reduction, a finding that may be related to the integrity of the distant part of the nerve. The lesions destroyed the nerve fibers at the point of the ganglion, while the distant part of the branch remained intact and could conduct the potentials. In addition, the selective damage of pain-mediating small A-δ and C fibers with preservation of A-β fibers at 80°C[9,20,21] may be another reason for this observation.

The mechanism by which RFTC works remains unclear. The study by Letcher and Goldring[15] demonstrated that the compound action potentials of A-δ and C fibers (nociceptive fibers) in nerves are blocked at temperatures lower than those that block larger A-α and A-β fibers, which carry tactile sensations. Therefore, the temperature-dependent selective destruction of A-δ and C fibers was achieved. However, some histological studies have demonstrated that lesions that nonselectively destroyed all nerve fibers did not spare the myelinated fibers. Nevertheless, the selective preservation of touch perception after RFTC has been established by clinical observations. Our findings tend to conform to the findings of Letcher and Goldring.[15] The main components of STAPs observed represent the activity of A-α and A-β fibers, which have high conduction velocities of 70–120 m/s and large amplitudes. Those fibers were preserved at high temperatures, and thus the amplitude appeared almost the same before and after RFTC.

In this study, the direct motor responses (M-waves) showed little intersubject variation. When the tip of the electrode was closer to the third division, the masseter was easily activated. In such cases, the potentials were probably 16–23 msec later than sensory potentials from the third division, which may have resulted from the delay of the neuromuscular junction; moreover, they were followed by several low-amplitude potentials of 0.1 to 0.3 mV, which may have been attributable to the anatomical features of the muscle and nerve. The potentials, which present as small unstable jitters, may be attributed to the discrete distribution of the stimulating current in different components of the nerve.[2]

Conclusions

This is a practical and sensitive method to assess the location of the radiofrequency tip by needle records of probes inserted subdermally near the supraorbital, infraorbital, and mental foramina and the masseter muscle. From the research data, it is apparent that the technique cannot completely substitute for patient verbal responses or become the gold standard for locating the radiofrequency cannula, and general anesthesia is still not recommended. Nonetheless, this method can improve the accuracy of electrode placement at the rootling/ganglion, when used in combination with EMG and the verbal response method. The approach is helpful in uncooperative patients, and it may be used to predict and decrease the complication of masseter weakness. The use of these complementary techniques might increase the chances of treatment success.

Acknowledgments

We thank Professor Guangyan Yu for medical editing and Dr. Kan Wang for data collection.

Disclosure

The authors report no conflict of interest concerning the materials or methods used in this study or the findings specified in this paper.

Author contributions to the study and manuscript preparation include the following. Conception and design: Cai, Lin. Acquisition of data: Lin. Analysis and interpretation of data: Cai, Lin. Drafting the article: Cai, Lin, Lu. Critically revising the article: all authors.

Reviewed submitted version of manuscript: all authors. Approved the final version of the manuscript on behalf of all authors: Cai. Administrative/technical/material support: Zhai. Study supervision: Zhigang, Lin.

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Manuscript submitted November 13, 2013.
Accepted August 19, 2014.
Please include this information when citing this paper: published online October 3, 2014; DOI: 10.3171/2014.8.JNS132484.
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