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The surgical treatment of chronic pain: destructive therapies in the spinal cord

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Average life spans and general health status have vastly extended and improved during the age of science and technology. Rates of cancer and age-related degenerative diseases have also increased, however [1]. Despite many improvements in medicine, pain is still an important public health problem and is maintaining its importance in medical practice. The development of more efficient physiologic techniques in surgical applications continues to demand significant effort. Minimally invasive procedures have recently been replaced by highly aggressive and complicated methods. Ablative procedures based on lesioning of the pain conduction system are described as neuroablative methods in medical practice. The term *ablative* as defined in *Webster's Third New International Dictionary* describes ‘‘removal of an organ or part by surgery’’ [2]. Nevertheless, procedures destroying the pain pathways should be described as ‘‘destructive surgery.’’ Precise controlled lesions in the pain pathways can be made with the help of minimally invasive stereotactic methods in our daily practice. The location of the pain tractus (target) can be demonstrated morphologically by neuroradiologic methods (eg, CT, MRI), whereas the function of the tractus and its environment can be evaluated by neurophysiologic tests (eg, impedance measurements, stimulation, evoked potentials). Finally, controlled lesions can be made with the patient's cooperation while maintaining the desired functions. These concepts are central to a new version of destructive pain surgery. In this article, CT-guided procedures are presented in three basic groups: CT-guided cordotomy, CT-guided trigeminal tractotomy-nucleotomy (TR-NC), and CT-guided extralemniscal myelotomy.

CT-guided percutaneous cordotomy

Lesioning of the lateral spinothalamic tractus (LST) in the anterolateral spinal cord is known as cordotomy (Fig. 1A). The name ‘‘cordotomy’’ was given by Schuller [3], and the first cordotomy was carried out by Martin at Spiller's instigation [4]. In the beginning, cordotomy operations were performed in the upper thoracic region using an open technique with a posterior approach. Anterior open cordotomy was described by Collis [5] and Cloward [6] in 1964 but was not widely used. In 1963, Mullan [7] described the percutaneous cordotomy technique using a radioactive-tipped strontium needle. In 1965, Rosomoff et al [8] described a percutaneous cordotomy technique using a radiofrequency (RF) electrode system. Classic cordotomy was widely used with the help of a radiographic visualization system, stimulation, and impedance measurements. Despite the use of contrast material, radiographic imaging did not demonstrate the spinal cord and real-time target-electrode relation during the procedure. Direct visualization of the spinal cord with CT imaging during the cordotomy gave a new dimension to cordotomy practice [9,10]. With the help of CT guidance, direct visualization of the spinal cord was obtained. Diametral measurements of the spinal cord were made for each patient, and every step of the procedure was demonstrated in real-time with CT imaging. This morphologic visualization can

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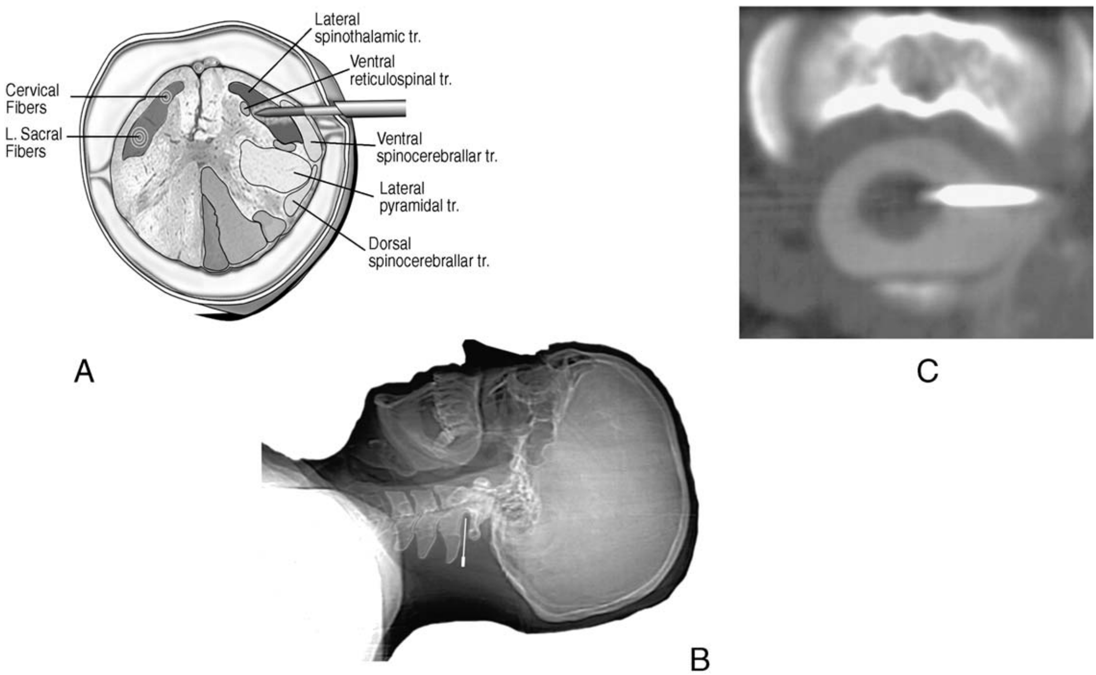

Fig. 1. (*A*) Topographic localization of the tractus and representation of target-electrode relations at the C1 to C2 level. (*B*) Lateral scanogram demonstrating the cannula in C1 to C2. (*C*) Final position of the electrode in axial CT.

be obtained with CT or MRI. MRI guidance needs special instrumentations because of artifact [9–12].

The target in cordotomy is the LST. The LST is located in the anterolateral part of the spinal cord and carries information about pain and temperature as well as some tactile information [13]. The organization of fibers from outside inward is as follows: superficial pain, temperature, and deep pain. The LST has a somatotropic relation to fibers from higher levels (eg, arm, chest) laminating anteromedially and to fibers from lower levels (eg, leg, sacrum) laminating posterolaterally [13]. This segmentation provides the opportunity for selective cordotomy and is used particularly for bilateral lesioning in the posterolateral LST for denervating the sacral and lumbar area (bilateral selective cordotomy). Bilateral denervation of the anteromedial region is not widely used; because of the close proximity of the reticulospinal tractus, bilateral lesioning of this tractus may cause respiratory complications (sleep-induced apnea) [14]. The pyramidal tract is usually located posterior to the dentate ligament (see Fig. 1A). There is much variation in the size and location of the ventral corticospinal tract; sometimes, it does not decussate. Because decussation sometimes extends from the obex to the C1 level, contralateral leg weakness may also occur if the lesion is made too high. The ventral spinocerebellar tract is located in the lateral part of the LST (see Fig. 1A). Multiple puncture during the procedure increases the risk of ataxia in this region. It must be remembered that the diameter of the spinal cord ranged from 7 to 11 mm anteroposteriorly and 9 to 14 mm transversely in our series; thus, active electrode calibration must be made for each patient [15].

Cordotomy is the best method for intractable pain transmitted in LST. For this reason, the best candidates are patients with unilateral somatic cancer pain and patients who have compression of the plexus, roots, or nerves. In our experience, the best results were obtained in somatic cancer pain patients who had local unilateral cancer pain, which is effectively denervated by cordotomy. Patients with lung mesothelioma and pulmonary carcinoma are accepted as risky patients for radiographically guided cordotomy. With the new version of cordotomy (CT guidance), however, this group can be treated easily and successfully [16,17]. In our experience, these patients were considered the best candidates for

CT-guided cordotomy. Upper extremity and chest pain was safely and selectively denervated by CT-guided selective cordotomy [16,17]. Tasker [18] defined two types of pain as indications for cordotomy. One is intermittent, neuralgia-like, shooting pain into the legs associated with spinal cord injury, which is typically at the thoracolumbar level. The other type is evoked pain—allodynia or hyperpathia—associated with neuropathic pain syndromes that arise from peripheral neurologic lesions [18].

Bilateral somatic intractable pain in the lower body and extremities can be controlled by CT-guided, unilateral, or bilateral selective cordotomy [19]. If a patient has a short life expectancy of 2 to 5 months, Gybels [20] proposed administering cerebrospinal fluid (CSF) opioid infusions and performing percutaneous neurolytic procedures instead of percutaneous cordotomy. Today, because of modern imaging techniques and advances in electrode technology, cordotomy can be safe and effective. Therefore, we believe that CT-guided percutaneous cordotomy should be considered the treatment of choice, even before morphine therapy. Cordotomy is contraindicated in patients with severe pulmonary dysfunction, patients who are unable to stay in a supine position for 30 to 40 minutes, and patients whose partial oxygen saturation is less than 80%. For patients with bilateral intractable pain of the chest and arms, we do not recommend bilateral high cervical cordotomy because of the high risk of respiratory problems [14,21].

Percutaneous cordotomy is routinely performed using an RF system consisting of a generator and specially designed needles and electrodes. The generator system must comprise an impedance measurement system, stimulation capabilities, and temperature monitoring of the electrode system. Several systems are available, which are manufactured by Diros Technology (Toronto, Ontario, Canada), Electa (Stockholm, Sweden), Howmedica-Leibinger (Freiburg, Germany), and Radionics (Burlington, MA). Different types of needle-electrode systems, all with their own standards, are available for percutaneous cordotomy; therefore, electrical parameters valid for one type cannot be effectively applied to another. The diameter and length of the uninsulated tip of the electrode are critical, because lesion size is directly related to these parameters. Thus, all parameters must be calibrated by making lesions in egg white before intraoperative application. We use the Kanpolat cannula and the KCTE electrode kit (Radionics), which contains 20-gauge thin-walled needles with plastic hubs designed to avoid imaging artifact problems [22].

Patients should have fasted for 5 hours before the operation. If required, neuroleptic anesthesia should be given at a dose that does not affect patient cooperation during the procedure. In each case, a cranial CT scan must be taken to rule out a mass lesion caused by metastasis, because this would be a contraindication to performing a cordotomy.

Contrast material should be administered into the subarachnoidal space of the spinal cord. If the patient's clinical condition permits lumbar puncture, the contrast agent (240-mg/L Iohexol, 7 mL) is administered by this route 20 to 30 minutes before the procedure. In this case, the patient should be kept in the Trendelenburg position before admission to the CT unit. If the patient's general condition is not suitable (lumbar scar or lumbar spondylosis), the contrast agent (240 mg/L-Iohexol, 5 mL) can be introduced laterally at the C1 to C2 level at the beginning of the procedure. The procedure is routinely performed in the CT unit. A lateral scanogram is then obtained demonstrating the needle position, followed by an axial scanogram using a 1-mm slice thickness. Diametral measurements of the spinal cord are taken to be used for adjustment of the inserted part of the active electrode as described below. Because CT-guided percutaneous cordotomy is performed in the CT unit, the patient is placed on the CT table in the supine position. The patient's head is kept in flexion, and the longitudinal axis of the cervical spine must be kept perfectly straight. The head is immobilized with a fixation band.

A 20-gauge plastic hub needle specially designed for CT-guided procedures is used. Because of the risk of distortion during insertion, smaller gauge needles are not acceptable. During every step of injection of the local anesthetic agent, negative pressure must be applied to check major vessel puncturing. After injection of the local anesthetic agent, the cordotomy needle is inserted inferior to the tip of the mastoid process in a vertical plane perpendicular to the axis of the spinal cord. It is critical that the needle not be rotated during the procedure.

Placement of the needle at the C1 to C2 level can be visualized in the lateral scanogram (see Fig. 1B), and the direction of the needle is manipulated toward the anterior aspect of the spinal cord with the help of axial CT sections. Ideal placement is 1 mm anterior to the dentate ligament for lumbosacral fibers and 2 to 3 mm anterior for thoracic and cervical fibers. The needle is in the ideal position if it is nearly perpendicular to the spinal cord. After achieving the ideal position of the needle tip, the straight or curved electrode is inserted (see Fig. 1C). Impedance measurements are taken to identify whether the active electrode tip is in the CSF, in contact with the spinal cord, or inside the spinal cord, but they do not supply information about the depth of penetration. These measurements should be less than 400 Ω when the electrode system is in the CSF and greater than 1000 Ω when the electrode system is inside the spinal cord. Real-time axial CT slices demonstrate depth and localization of the electrode tip. The second step of the procedure indicates the functional evaluation of the target with stimulation. Stimulation with low frequencies (5 Hz, 0.2–1 V) causes ipsilateral trapezius muscle contractions, indicating that the electrodes are within or near the anterior gray matter. In high-frequency stimulation (50–100 Hz, 0.5–1 V), patients describe sensations like contralateral tingling if the electrode system is in the target. As a result of the use of CT imaging, there is no possibility of mislocalization of the active electrode system; however, because of variations in the tracts (especially of the corticospinal tract), ipsilateral motor responses can be observed during stimulation. This is the most important aspect of stimulation during this type of procedure; however, in more than 300 CT-guided procedures, we observed no anatomic variations.

Bilateral high cervical cordotomy is rarely used in practice. In the classic series, high complication rates were reported [21,23]. In our practice, smaller lesions are preferred and 0.30-mm electrode systems are used. This technique is best for cases with lower abdominal or lower body pain. The technique is not recommended for bilateral upper body pain, especially that located in the bilateral chest region, because of the high rate of respiratory complications.

Because of the risks associated with lateral high cervical cordotomy, an anterior percutaneous cordotomy was proposed by Gildenberg et al [24] as a method of lesioning the LST in lower cervical spinal cord segments by a percutaneous approach. In 1995, Fenstermaker et al [25] performed a CT-assisted anterior percutaneous cordotomy and used the same technique bilaterally in three cases. They used an anterior approach on one side and a lateral approach on the other side for bilateral cases. This option could be especially useful for bilateral percutaneous cordotomy.

We performed CT-guided percutaneous cordotomy in 187 cases. Most of these patients (176 cases) were suffering from intractable unilateral pain because of malignancy. Pulmonary malignancies (57 cases), mesothelioma (20 cases), and Pancoast tumors (15 cases) represented most of the cases (53%). Additionally, there were 21 patients with gastrointestinal carcinoma, 21 with metastatic carcinoma, and 42 with other types of malignancies. The procedure was also applied to 11 cases with benign pain: 1 patient had a single root avulsion of the brachial plexus imitating phantom pain, 1 was suffering from postsurgical hip and leg pain caused by epidural fibrosis, and 1 had a spinal perineural cyst. The others had gunshot trauma, tuberculosis, electrical burns, postherpetic neuralgia, and failed back surgery. The initial success rate of CT-guided percutaneous cordotomy was 96%. In cases with malignancies, this rate was also 96%. In 141 cases in the cancer group (83%), only the painful region of the body was relieved from pain, thus achieving selective cordotomy. In 11 cases, percutaneous cordotomy was successfully applied bilaterally.

The initial success rate of 3742 radiographically guided percutaneous cordotomy cases collected by Lorenz [23] was 75% to 96%. In another study reported by Sindou et al [26], which compiled results taken from an analysis of 171 personal cases and a review of 37 series from the literature, totaling 5770 radiographically guided cases, pain relief was evaluated independently in cancerous and noncancerous patients. In the cancer group (2022 cases), anterolateral cordotomy was effective in providing satisfactory pain relief during the survival period in a significant number of patients (in 75% at 6 months and in 40% after 1 year). A comparison of these results with our series is not realistic because all these procedures were performed with radiographic guidance instead of CT imaging.

In the past, classic percutaneous cordotomy was associated with high complication and low success rates as well as mortality. There are two reasons for complications. First, the needle-electrode may be mislocalized and thus may not carry out its function on the required tract but may affect other tracts. With CT guidance, this possibility is almost totally overruled because of direct imaging, which provides real-time morphologic information. The second important reason for complications is involuntary enlargement of the lesioned area, causing interruption of unintended functions. This possibility is also minimal with the use of

2-mm diameter thermic lesions with the special electrode system. As a result of these advantages, no mortality or persistent complications were encountered in our series. Five cases of motor dysfunction, three of ataxia, one of urinary retention, and three of hypotension were observed as temporary complications. Only four cases of postcordotomy dysesthesia and one case of Horner's syndrome were accepted as true complications. In cervical cordotomies, it has already been mentioned that respiratory dysfunction is the principal complication and can be fatal [14,21]. The risk is higher in patients with preexisting functional respiratory disorders. Sleep-induced apnea has been reported as a serious and fatal complication caused by lesioning of the reticulospinal tract in the bilateral anteromedial spinal cord [14,21,27]. When a bilateral cordotomy is performed, respiratory functions must be carefully observed after surgery. For this reason, 11 bilateral cordotomies were performed in cases of pain only below the chest region. Ataxia, usually transient, was noticed as the most common complication. Some authors have indicated that if difficulty with urination is present, it is usually temporary. Impotence, especially after bilateral cordotomy, must be expected in most cases, although explanation of the mechanism is speculative.

Trigeminal tractotomy-nucleotomy

Lesioning of descending trigeminal tract in the medullary level at the occiput-C1 level is known as trigeminal tractotomy [28]. Destruction of the nucleus caudalis at the occipitocervical level is known as trigeminal nucleotomy, whereas lesioning of the whole substantia gelatinosa of the nucleus caudalis is known as the nucleus caudalis dorsal root entry zone (DREZ) lesion [29,30]. Pain fibers from cranial nerves VII, IX, and X join and descend with the spinal tract of the trigeminal nerve into the upper spinal cord [31]. The topographic localization of the nociceptive fibers from the cranial nerves makes this region an eloquent target for destruction by neurosurgeons to relieve dysesthetic, neurogenic, or deafferentation types of craniofacial pain (Fig. 2A).

In 1938, the first tractotomy was performed by Sjöqvist [28]. In 1942, White and Sweet [32] observed hypoalgesia in the regions innervated

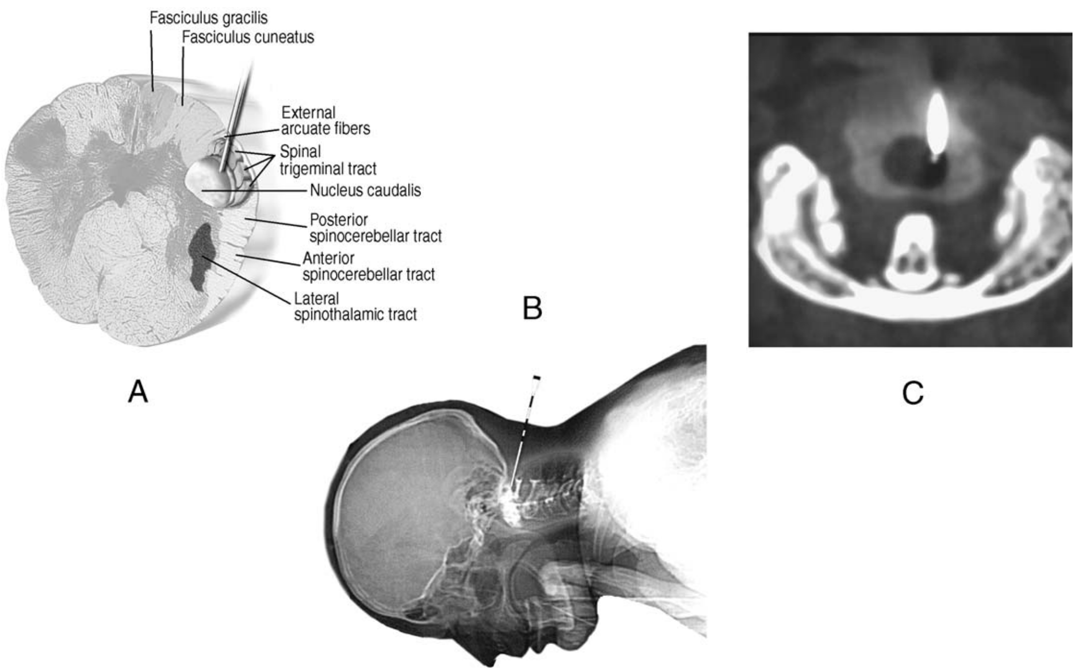

Fig. 2. (*A*) Topographic localization of the tractus and schematic representation of CT-guided trigeminal tractotomy-nucleotomy. (*B*) Lateral scanogram demonstrating cannula in C1-occiput. (*C*) Position of the needle-electrode system at the same level.

by cranial nerves VII, IX, and X after trigeminal tractotomy. Broadal [33] reported ipsilateral analgesia involving the face, mouth, concha of the auricle, posterior part of the tongue, tonsil, and pharynx in four patients after tractotomy performed by Torkildsen in 1947. In 1954, Kunc [34] developed a high cervical approach technique, and he too used the procedure selectively to relieve glossopharyngeal neuralgia with great success. Crue et al [35] and Hitchcock [36] independently developed a stereotactic percutaneous technique using RF thermocoagulation, which enabled them to perform the first stereotactic trigeminal tractotomies. Schvarcz [29] has used this technique since 1971, naming the procedure ''trigeminal nucleotomy'' to emphasize the significance of creating lesions primarily in the second-order neurons at the oral pole of the nucleus caudalis. In 1986, Nashold et al [30] described another open surgical technique, naming it the ''trigeminal nucleus caudalis DREZ operation,'' in which they destroyed the nucleus extensively with RF between the dorsal root of C2 and 5 mm above the obex. In 1989, we developed a percutaneous technique for trigeminal TR-NC guided by CT [11,37,38].

Trigeminal afferents that carry the sensations of pain and temperature bifurcate on entrance into the pons and send a caudalward branch, called the descending trigeminal tract, into the medulla; these fibers terminate in the spinal trigeminal nucleus [28,39]. The descending trigeminal tract overlies the spinal trigeminal nucleus in the posterolateral part of the spinal cord at the cervicomedullary junction. Primary sensory fibers from cranial nerves VII, IX, and X also enter the descending tract of the trigeminal nerve, and all the nociceptive afferents of the cranial nerves form the descending cranial nociceptive tract [40,41]. The three divisions of the trigeminal nerve have a specific topographic organization in the descending trigeminal tract: fibers from the mandibular dermatome (V3) are located in the dorsal part of the tract, ophthalmic fibers (V1) are located ventrolaterally, and maxillary fibers (V2) are located between them. The fibers from cranial nerves VII, IX, and X lie slightly medially behind the tract.

The trigeminal sensory nucleus consists of three nuclei extending from the rostral spinal cord to the midbrain: spinal, principal, and mesencephalic trigeminal nuclei. Trigeminal afferents that carry the sensations of pain and temperature separately from other sensory modalities descend in the spinal trigeminal tract in the medulla and terminate in the spinal trigeminal nucleus.

The spinal trigeminal nucleus has three distinct subdivisions along its pontospinal extent: the nucleus oralis, located rostrally between the pons and medulla; the nucleus interpolaris, located intermedially; and the nucleus caudalis, located at the medullospinal junction and extending down to the level of the C2 segment. The nucleus caudalis represents the substantia gelatinosa, and there is an extensive overlap between facial and high cervical afferents, where afferents VII, IX, and X also end. The secondary caudalis neurons begin to fire like those contained in an epileptogenic area after deafferentation, and these neurons may provide the neuropathologic basis for central pain, such as in anesthesia dolorosa, postherpetic pain, and trigeminal dysesthesia. Destruction of the oral pole of the nucleus caudalis plays a special role in pain relief. Schvarcz [29] attributed particular importance to destruction of the oral pole of the nucleus caudalis, which probably acts on the pathology site, removes the pool of neuronal hyperexcitability, eliminates convergence, and severs the ascending intranuclear polysynaptic pathways. The nucleus caudalis of the trigeminal nerve lies between 5 mm above the obex at the posterolateral part of the bulbus and spinal cord and the dorsal root of the C2 segment (approximately 20 mm below the obex). At the medullobulbar junction, it is located between the lateral border of the dorsal column (fasciculus cuneatus) and the rootlets of the spinal cord in the axial section (see Fig. 2A) [30,39].

There is a topographic representation of the ipsilateral face on the spinal tract of the trigeminal nerve (ie, the most central areas of the face terminate highest on the nucleus caudalis, the most peripheral areas of the face terminate lowest). This is called ''onion-skin organization'' and causes the central area of the face to be spared from hypoalgesia after the nucleus caudalis DREZ operation if the lesions do not extend above the obex [30,31,39].

The dorsal spinocerebellar tract is located immediately lateral to the descending trigeminal tract, and the external arcuate fibers cover the tract posteriorly; thus, ataxia of the ipsilateral extremities usually accompanies extensive tractotomy, nucleotomy, and nucleus caudalis DREZ operations [30,31,40]. The LST is located anterior to the descending trigeminal tract and the nucleus caudalis. Anterior lesions may produce analgesia on the contralateral body. The funiculus cuneatus is located just posteromedial to the descending cranial nociceptive tract and to fibers VII, IX, and X, and a lesion involving the funiculus may produce loss of proprioceptive sensation in the lower extremities [41].

In the practice of trigeminal tractotomy and nucleotomy, the target is the descending trigeminal tract and the nucleus caudalis, which are located at the medullospinal junction at the occiput-C1 level (see Fig. 2A).

Spinal cord diameters in this region are given as 18 mm transversely and 10 mm anteroposteriorly. In our experimental and clinical studies, these measurements were obtained as 9.3 to 14 mm transversely (mean: 11.6 ± 0.76 mm) and 7.0 to 12.8 mm anteroposteriorly (mean: 9.13 ± 0.83 mm) [15]. The distance between the dura and the skin at the occiput-C1 level has been measured with CT scans and has been found to range from 40 to 65 mm (mean: 48 mm). Because of these variable diametric measurements, spinal cord diameters must be measured before the operation, and insertion of the active electrode should be calibrated according to these data.

The indications for trigeminal tractotomy, nucleotomy, and nucleus caudalis DREZ operations are nearly the same. If we would like to lesion a large area, the nucleus caudalis DREZ operation could be chosen as an invasive procedure. If there is a chance of controlling the pain with small lesions in this area, however, TR-NC could be chosen as the initial procedure. Neurosurgical operations on the descending cranial nociceptive tract and the trigeminal nucleus caudalis are indicated especially in patients with craniofacial dysesthetic or deafferentation pain. Cases appropriate for treatment with trigeminal TR-NC operations include those diagnosed with anesthesia dolorosa; postherpetic dysesthesia; atypical facial pain; dysesthetic sequelae after previous trigeminal surgery; posttraumatic neuropathy; and head, neck, or facial pain caused by malignancy [34,35,42]. Patients with vagal, glossopharyngeal, or geniculate neuralgia may be the best candidates for such operations [37].

The classic needle-electrode system described previously for CT-guided cordotomy is recommended for this procedure [22].

Preoperative preparation is the same as for CT-guided cordotomy. The patient is placed on the CT table in the prone position. With the help of the head support of the CT table, the patient's head is kept in slight flexion. The chest must be elevated and supported with soft pads, and the head is fixed with a fixation band. Because the TR-NC procedure is more painful than the previously described techniques, neuroleptic anesthesia must be given during the lesioning; thus, nasal oxygen tubing is fixed to the patient's nostrils. A detailed description of the technical aspects of the procedure has already been provided [38]. The steps of the procedure are shown in Fig. 2.

Fifty-three patients underwent CT-guided TR-NC. Complete or partial satisfactory pain control was obtained in 45 patients (85%). Good results (complete or satisfactory pain control in most of the patients) were obtained from the groups with glossopharyngeal neuralgia and geniculate neuralgia. In 13 cases of glossopharyngeal neuralgia, pain control was obtained in 8 patients and no recurrence was seen. In 5 cases, pain control was obtained but recurrence was seen in the long-term follow-up period. In 2 cases, rhizotomy of nerve IX and microvascular decompression were performed and pain control was obtained. Nucleus caudalis DREZ operations were performed in 2 cases, and in 1 patient, the pain was totally controlled. In the other patient, pain control was achieved with carbamazepine. In 4 cases of geniculate neuralgia, pain control was obtained in 3 cases with TR-NC. In 1 case, pain control was not obtained; a nucleus caudalis DREZ operation controlled pain attacks, but the patient died dramatically of severe pulmonary edema on the second postoperative day. In the series of cases with craniofacial malignancy (11 cases), complete pain relief was achieved in 9 cases. The remaining 2 patients subsequently underwent a nucleus caudalis DREZ operation; pain was completely controlled in the first patient and partially but unsatisfactorily in the second patient. We must remember that craniofacial malignancies usually infiltrate the area of nerves V, VII, IX, and X. For this reason, with the help of TR-NC, cancer pain of these nerve areas can be denervated and controlled. In 7 of 16 cases with atypical facial pain, complete pain control was achieved. In 6 cases, partial satisfactory pain control was achieved. In the 2 cases in which TR-NC was ineffective, a subsequent nucleus caudalis DREZ operation was performed, but this was effective in only 1 case. Two (including the patient with bilateral trigeminal neuralgia) of 3 patients with failed trigeminal neuralgia were treated effectively with TR-NC, and 1 patient responded poorly. That patient underwent a nucleus caudalis DREZ operation, and partial satisfactory pain control was obtained. Complete pain control was obtained in 2 of 4 cases with postherpetic neuralgia. In the third case, pain control was obtained by a nucleus caudalis DREZ operation. In the fourth, pain control was not obtained. Finally, in 1 case with anesthesia dolorosa, pain control was not achieved.

CT-guided trigeminal TR-NC is an effective and safe procedure with a low risk of complications. In tractotomy and nucleus caudalis DREZ lesions, the most important complication is ataxia, which is caused by lesioning of the dorsal spinocerebellar tract [30,43]. In our series, temporary ataxia was the only complication and was observed in five cases; all cases resolved within 2 weeks. No mortality was observed. In conclusion, CT-guided TR-NC is an effective procedure. The technique is safely performed by identifying the morphology, evaluating the tractus by stimulation, and finally obtaining good pain relief with controlled lesioning of the sensory areas of nerves V, VII, IX, and X.

Extralemniscal myelotomy

The procedure known as midline myelotomy is based on stereotactic lesioning of the central canal region at the C1-occiput level (Fig. 3). This group of procedures, using a percutaneous or open method, consists of the creation of central spinal cord lesions at different levels [44,45]. The first operation was performed by Hitchcock [44] in 1968 to destroy the upper cervical commissural fibers.

Later procedures on the central cord showed that the lesions caused relief of pain not only in the upper body and extremities but in the lower body and lower extremities as well as relief of visceral pain, pain located at the midline, and even central pain [44]. These observations caused a change in the indications and limitations of central cord lesions. Schvarcz [41] stated that "The procedure, however, was not aimed at severing segmental decussating fibers, but at interrupting selectively the extralemniscal system. That is an ascending nonspecific polysynaptic pathway." He named the procedure "extralemniscal myelotomy." Gildenberg and Hirshberg [46] performed limited myelotomy with an open technique at the Th-10 level for similar purposes. Nauta et al [47] used central cord lesioning by an open method at the Th-7 and Th-4 levels using a punctuate incision with a 16-gauge needle. In the past, percutaneous extralemniscal myelotomy has conventionally been performed with the aid of radiographic visualization at the occiput-C1 level, although we now recommend using the technique

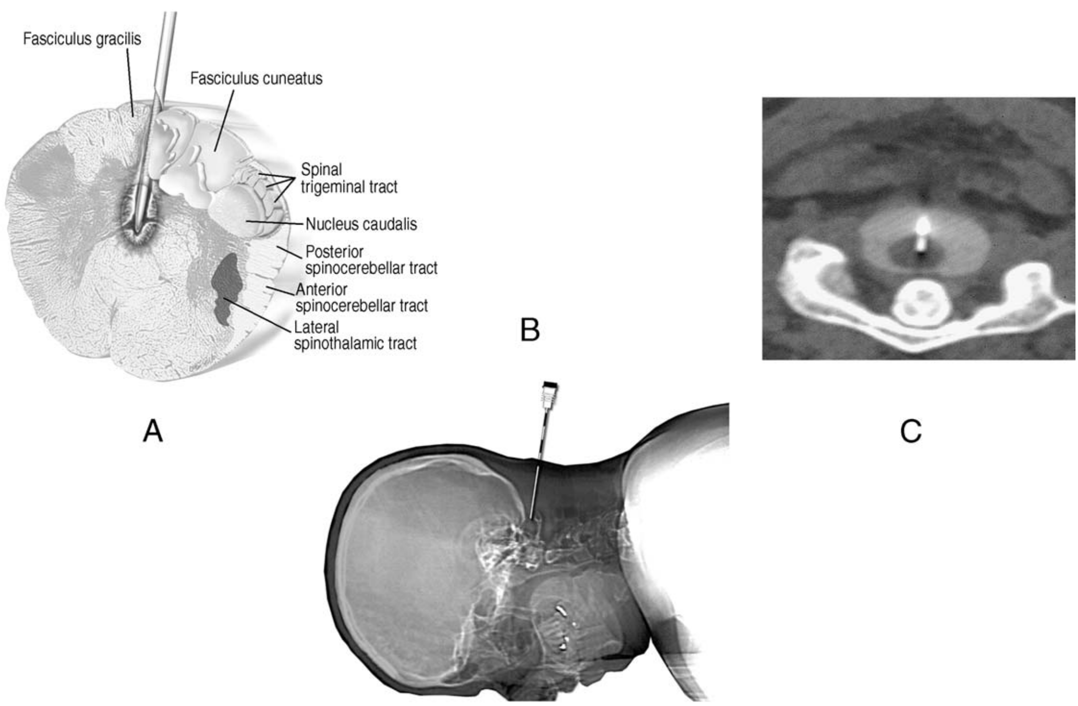

Fig. 3. (*A*) Topographic localization of the target and representation of CT-guided extralemniscal myelotomy. (*B*) Lateral scanogram demonstrating cannula in C1-occiput. (*C*) Position of the needle-electrode system at the same level.

with CT guidance [9]. The inserted electrode tip should be adjusted in accordance with the spinal cord diameters measured by CT visualization. Another advantage of CT guidance is that it allows visualization of the active electrode location in the spinal cord [9]. The tip of the active electrode may be redirected if needed during the procedure, based on the images (see Fig. 3C).

Extralemniscal myelotomy at the occiput-C1 level is an operation that was developed after empiric observations by Hitchcock [44]. He noticed that even small lesions in the upper central cord may cause relief from visceral pain, central pain, and pain in the midline of the body and/or lower extremities. Additionally, Gildenberg and Hirshberg [46] reported that similar lesions may be effective in controlling pain not only in the upper spinal cord but at the Th-10 level. Such an effect could not be explained by interruption of the segmentally decussating fibers, which are the target in commissural myelotomy. Additionally, Shealy et al [48] found bilateral activity elicited by C-fibers in the central cord region. After these observations, Schvarcz [40] stated that the pain relief mechanism may be related to interruption of an extralemniscal, multisynaptic, nonspecific ascending system. In recent human and experimental studies, a new focus has been given to the posterior funiculus of the spinal cord [48,49]. These studies support the theory that there is a pathway that transmits visceral pain in the posterior funiculus of the spinal cord and that extensive cross-connections within the propriospinal system are densely grouped at the base of the dorsal funiculi. Al-Chaer et al [49] stated as an explanation for midline myelotomy that interruption of the dorsal column fibers in the upper central cord may tip the balance away from pain perception, which would account for pain relief in the absence of demonstrable sensory loss. There are numerous procedures and mechanisms described in this section. There is insufficient evidence to explain the mechanisms and effects of these procedures, however, so we must accept that the central cord region is an undiscovered but important target to control intractable visceral pain.

The ideal candidates for central cord lesions are patients having intractable pain with malignancies in the abdominal or pelvic region. Because of our limited experience, we only use this method for this select group of patients.

The classic needle-electrode system described previously for CT-guided cordotomy is again recommended for this procedure. Preoperative preparation comprises the same procedure described previously for cordotomy.

The patient is placed on the CT table in the prone position. With the help of the head support of the CT table, the patient's head is kept in slight flexion. The chest must be elevated and supported with soft pads, and the head is fixed with a fixation band. The technicalities of the procedure have already been described (see Fig. 3) [9,17,38].

CT-guided extralemniscal myelotomy was performed 18 times on 16 patients. Most had rectal, pancreatic, gastric, colon, or renal cell carcinomas causing intractable visceral pain. One exceptional patient had postparaplegic pain as the result of a gunshot wound, and another had chronic intractable visceral pain possibly caused by degenerative spinal cord disease. Total pain relief was achieved in 6 cases, partial satisfactory pain relief was obtained in 5 cases, and no pain control was achieved in 5 cases. In 10 cases in which larger electrodes were used, total pain relief was achieved in 5 cases and partial satisfactory pain relief was achieved in 3 cases, whereas pain persisted in 2 cases. Conversely, in the 6 patients in whom the smaller electrodes were used, total pain relief was achieved in only 1 case and partial satisfactory pain relief was achieved in 2 cases, whereas pain persisted in 3 cases. Postoperative neurologic examination of the patients revealed hypoesthesia and hypoalgesia in only 1 patient. No complications were observed.

Summary

Stereotactic pain surgery is accepted as a group of procedures. These are usually highly sophisticated and technically risky procedures. In practice, the most important part of this discipline is not the technical abilities of the surgeon, but selection of the most appropriate patients for the available procedures. We must remember that we are performing all these procedures with the cooperation of patients. The energy that is used for lesioning can be stopped when desired. The target we want to approach can be definitely and anatomically visualized and demonstrated, and the function of the target is evaluated with neurophysiologic impedance techniques and stimulation. Thus, if we are able to understand the language of the central nervous system, these are available, effective, and safe procedures in neurosurgical practice. We must remember that if intractable pain can be controlled by minimally invasive destructive techniques, the patients will not be dependent on implantable systems, drugs, and medical units. This independent lifestyle is a critical goal central to quality of life for patients having intractable pain.

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