Offprint from
Advances and Technical Standards in Neurosurgery, Vol. 32
Edited by J.D. Pickard

Percutaneous destructive pain procedures on the upper spinal cord and brain stem in cancer pain: CT-guided techniques, indications and results

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With 16 Figures

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Abstract

In the century of science and technology, the average life span has increased, bringing with it an increase in the incidence of degenerative and cancer disease. Intractable pain is usually the main symptom of cancer. With the advancement in technology, there is a large group of patients with intractable pain problems who can benefit from special help medically or surgically. Destructive pain procedures are necessary to control the cancer pain and are based on the lesioning of the pain conducting pathways. Percutaneous cordotomy, trigeminal tractotomy and extralemniscal myelotomy are special methods based on lesioning of the pain conducting pathways. The procedure consists of obtaining direct morphological appearance of the upper spinal cord and surrounding structures by computed tomography (CT). The next step is functional evaluation of the target and its environment by impedance measurement and stimulation. The final step is terminated with controlled lesioning obtained by a radiofrequency system (generator, needles, electrode system).

In the last two decades, CT-guided destructive procedures were used as minimally invasive procedures as follows: percutaneous cordotomy (207 patients), trigeminal tractotomy-nucleotomy (65 patients), and extralemniscal myelotomy (16 patients). Most of these patients had cancer pain.

Minimally invasive CT-guided destructive pain procedures are still safe and effective operations for relieving intractable cancer pain in selected cases.

Keywords: Intractable cancer pain; percutaneous cordotomy; trigeminal tractotomy-nucleotomy; extralemniscal myelotomy.

Introduction

In the last two decades, the impact of technology in medical practice has highly dominated our lives. In this period, the terms quality of life, minimally invasive, robotic, high technology, high-tech, neuromodulation, and neurostimulation have become widely accepted. As a result, those surgical treatment methods utilizing high technology and appearing to be minimally invasive have gained widespread acceptance. Unfortunately, as a consequence of this process over time, some less technological but highly effective methods are neglected or discounted and become generally perceived as dangerous.

In pain surgery, some of the very important and effective procedures have basically been abandoned in developed western literature because of their risky application. Some pain-relieving procedures are currently described as destructive, minimally invasive, safe and effective, but they are rarely preferred in intractable pain treatment in cancer patients [38]. These procedures are usually described as "classically ablative" procedures. Definition of the term "ablation" according to Webster's Third New International Dictionary as "removal of an organ or part by surgery" does not reflect the true purpose of this technique [48]. Procedures destroying the pain pathways can be performed with the help of minimally invasive stereotactic methods in our daily practice.

The century of science and technology has witnessed an increase in our average life span. In other words, in the age of science and technology, we are living in a society of advanced age. Thus it is not surprising that the incidence of cancer in this society is higher than was observed in younger societies. It is commonly held that pain is the most classical symptom of cancer disease and is dominant in the terminal stages [10]. As scientists and neurosurgeons we must propose some effective and rational solutions for these patients. Recent technological improvement has facilitated the development of some effective and simple procedures in the treatment of cancer pain, yet they are still not widely used. In this paper, contrary to established opinion, we will present some safe and effective destructive procedures targeting a unique part of the human body for achieving control of intractable cancer pain. The described methods are based on destruction of pain-conducting pathways, but the most important difference is demonstrating the target and destructive elements of the pain destructive equipment (Kanpolat cannula and electrode kits and lesion generator, Cosman Company, Burlington, MA, USA) [18]. For this reason, we have termed this group of procedures as computed tomography (CT)-guided pain procedures [15, 17–19]. In this group, CT-guided percutaneous cordotomy, CT-guided trigeminal tractotomy-nucleotomy and CT-guided extralemniscal myelotomy are presented.

CT-Guided percutaneous cordotomy

The pain-conducting tractus was discovered in clinical observations. Müller was the first to report an isolated analgesia observed after lesion of the spinal cord [35]. In this case, the whole of one half of the spinal cord and both dorsal columns had been damaged by a stab wound. The results of the lesion were anesthesia to touch on both sides and analgesia of the side opposite to the lesion. A few years later, Gowers reported a case of localized injury to the anterolateral column at the level of the 3rd cervical segment, which resulted in complete analgesia with preservation of tactile sensation on the opposite half of the body. From this case, Gowers concluded that the afferent pathway for pain was located at the anterolateral column of the spinal cord [45]. The existence of the spinothalamic tract was evidenced in 1889 by Edinger based on degeneration experiments in amphibians and newborn cats. Schüller performed sectioning of the anterolateral tract in monkeys, and named the procedure chordotomie [41]. It was used for the first time for relief of intractable pain in humans in 1911 by open technique as proposed by Spiller and performed by Martin [46]. The procedure was independently performed by Foerster and Tietze in 1913 [6]. In 1920, Frazier published a series of six cordotomy patients [7]. After this publication, cordotomy was accepted as an important method of pain surgery. Traditionally, cordotomy was an effective method using a posterior approach. The anterior approach in the lower cervical region was described by Cloward and Collis, but has not been widely utilized [2, 3].

Cordotomy is predominantly performed in cancer patients who cannot tolerate open surgery because of their poor clinical condition. Thus, surgeons have searched for noninvasive modalities in the treatment of these patients. In 1963, Mullan *et al.* described and performed percutaneous cordotomy using radioactive-tipped strontium needle [32]. Because of the uncontrolled effect of the radioactive source, Mullan *et al.* later tried unipolar anodal electrolytic lesions in 1965 [34]. In the same year, Rosomoff *et al.* described the technique of percutaneous cordotomy using radiofrequency (RF) electrode system [40]. In the following years, this system was used with impedance measurements and some contrast agents for visualization [9, 47]. Percutaneous cordotomy was routinely performed with the help of X-ray. In 1986, together with my colleagues, I attempted to use CT visualization for pain surgery in the CT unit for extralemniscal myelotomy [15]. We published the first paper regarding CT-guided extralemniscal myelotomy two years later, in 1988 [15]. In the following years, we used CT guidance as a classical visualization method in percutaneous stereotactic pain procedures [15, 17, 19, 23–27].

Anatomic target

The main anatomic target is the lateral spinothalamic tractus located in the anterolateral part of the spinal cord. Anatomical details of the pain-conducting tractus and especially of the lateral spinothalamic tractus have been presented by us in many papers [24–27]. This target is approached at the C1–2 level (Figs. 1 and 2). Localization of the target is defined by CT visualization (Fig. 4). In our experimental and clinical studies, it has been demonstrated that diametral measurements of the spinal cord are not standard. For this reason, diame-

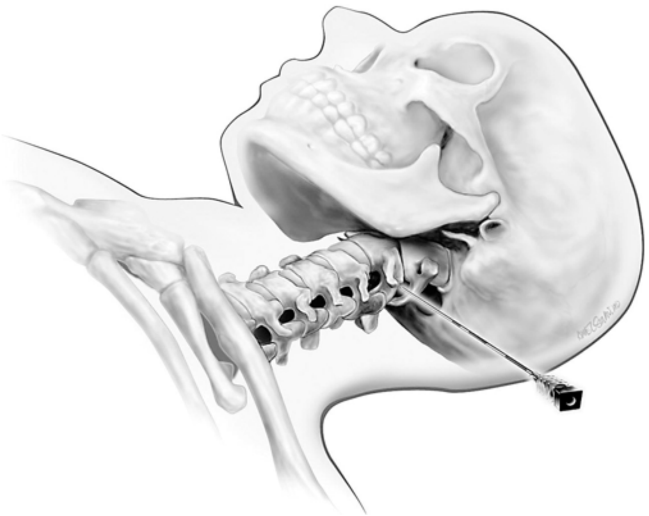

Fig. 1. Schematic drawing of percutaneous approach at the C1–2 level

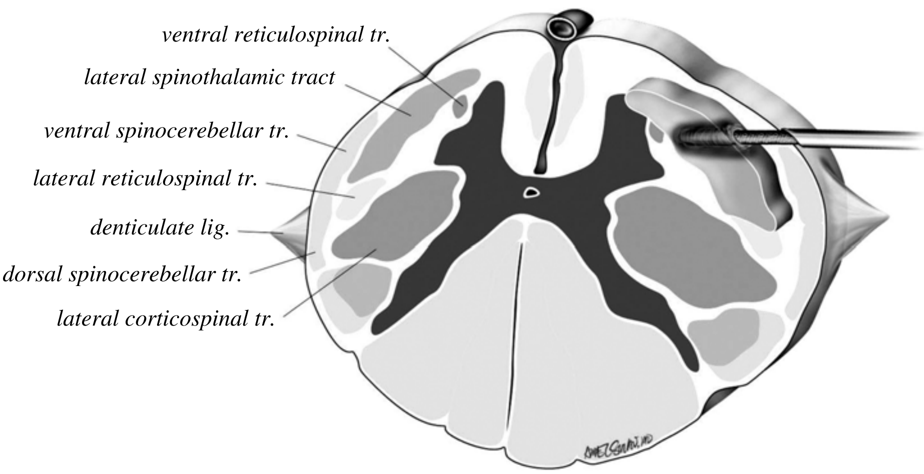

Fig. 2. Schematic drawing of the target-electrode relation and main anatomical structures in percutaneous cordotomy

tral measurements of the spinal cord are determined for each patient before the procedure and calibration of the inserted part of the active electrode is obtained with the help of these measurements [14].

Indications and contraindications

Cordotomy operation is principally based on the lesioning of the lateral spinothalamic tractus, which carries pain and temperature sensation. This fiber decussates in the spinal cord. For this reason, the procedure is performed contralateral to the pain site. In the past, the procedure was widely performed for benign and malignant intractable pain patients. In our daily practice, CT-guided percutaneous cordotomy is performed especially for cancer patients. The best candidates are those with unilateral localized intractable cancer pain, as seen in mesothelioma of the chest wall or carcinoma of the lower extremities, and those with unilateral localized pain problems [16, 17, 23]. Bilateral CT-guided cordotomy is chosen for the patient with intractable pain localized in the lower extremities [22]. Bilateral upper body pain is not accepted because of complication risk. There is a generally accepted opinion that cordotomy is chosen just after morphine therapy [10]. However, we recommend cordotomy just prior to initiation of narcotic agents, even if the patient's survival is less than six months. In the practice of intractable cancer pain treatment, there is a consensus dictating selection of these procedures usually in the terminal stage [50]. Our experience has shown, however, that if we are confident regarding the effectiveness of the procedure for intractable cancer pain, CT-guided percutaneous cordotomy before morphine therapy is a reasonable choice. The rationale of this strategy is based on the effectiveness and safety of the procedure observed over the course of our 20 years of clinical experience. Patients with severe pulmonary dysfunctions and in whom partial oxygen saturation is lower than 80% are not suitable candidates for cordotomy. We also do not employ percutaneous cordotomy if a patient's survival is less than three months. The most important consideration in percutaneous bilateral cordotomy is pain location. I personally do not perform bilateral cordotomy for bilateral upper body cancer pain. Another important contraindication for the procedure is the behavior of the patient and his/her family. The procedure should be considered carefully, particularly in patients receiving long-term treatment with opiate alkaloids, who possibly developed a dependency, and in cases of psychopathic family-patient relations [27].

Indications-contraindications of cordotomy have been summarized in Table 1.

Table 1

	Indications	Contraindications
Cordotomy	– Unilateral malignancies	– Behavior of the patient and her/his family
	– Lower extremities' pathologies (unilateral/bilateral)	– Bilateral upper extremities' pathologies
	– Failed back syndrome	– Severe pulmonary dysfunction
	– Chronic nociceptive painful conditions	

Technique

Preparation of the patient

The patient should be fasted for five hours before the procedure. The required dose of analgesics is given parenterally. The patient is informed before the procedure by the surgeon. Iohexol (7–8 mL of 240 mg/mL) is given 20–30 minutes before the operation by lumbar puncture. After injection of the contrast medium, the table is repositioned to trendelenburg position and it is kept 15 minutes to see the contrast in cervical region. If the general condition of the patient does not permit lumbar puncture, contrast material is injected during the procedure at the C1–2 level [17, 22, 27].

Positioning

As stated before, CT-guided cordotomy is performed in the CT unit. After the administration of contrast material, the patient is taken to the CT unit and placed on the CT table in the supine position [24–27]; the head is positioned on the headrest, flexed and fixed with band. The shoulders must be held low. The maximum comfort of the patient must be obtained; if necessary, some neuroleptic analgesics can be given [24–27]. Midazolam 0.5 mg/kg and fentanyl 1 μg/kg are used for neurolept anesthesia.

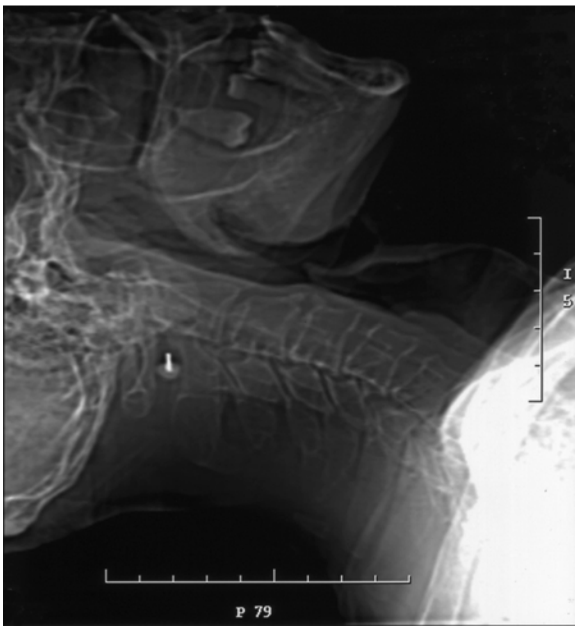

Fig. 3. Lateral radiograph of percutaneous cordotomy

Anatomic localization with CT

Before each procedure, routine cranial CT scan is obtained to exclude any intracranial mass lesions (metastasis, etc.). If such lesions are visualized, the procedure was not done. Routine lateral radiograph and axial CT slices of the C1–2 level are obtained. Diametral measurements of the spinal cord are taken, and distance between skin and dura is measured at the C1–2 level. The importance of these measurements described before [14]. The inserted portion of the active electrode is calibrated using diametral measurements of the spinal cord. Local anesthetic is given by separate inserted needle and cordotomy needle is inserted to approach the anterolateral part of the spinal cord at the C1–2 level. Ideal placement of the needle is initially just localized in the anterolateral part of the dura of the upper spinal canal. After every step of cannula movement, new CT slices are taken with lateral scanogram (Fig. 3). The new CT slices are not only for demonstrating the final position of the cannula but also for orienting where the tip of the cannula locates. In some cases, especially in cancer patients, who had radiotherapy before, the dura is very thick and difficult to puncture. If the puncture is painful, additional local anesthetic is given. Repeat CT slices can aid the surgeon in preventing improper puncturing. After the dural puncture, ideal localization of the tip of the cannula (Figs. 4 and 5) is 1 mm anterior to the dentate ligament for lumbosacral fibers and 2–3 mm anterior to the dentate ligament for thoracic and cervical fibers. After achieving the ideal positioning of the needle tip, the straight or curved electrode is inserted [17, 22–27].

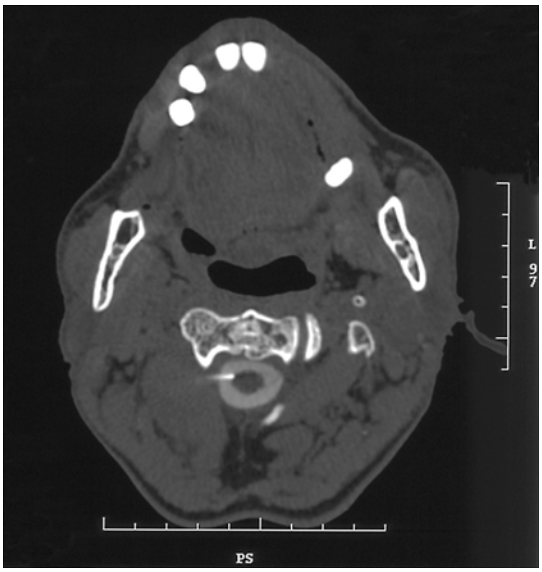

Fig. 4. Final position of the cannula on axial CT scan at the C1–2 level in percutaneous cordotomy

Physiologic localization

With the help of neurophysiological confirmation via impedance measurement and stimulation, functional response of the target is confirmed. Impedance measurements are taken to identify whether the active electrode tip is in the cerebrospinal fluid (CSF) (around 100 Ω), in contact with the spinal cord (around 300 or 400 Ω) or inside the spinal cord (more than 700 Ω). The target-electrode relationships are easily detected by direct visualization of the needle-electrode system under CT guidance [24, 27]. Figure 6a and b present the generator (Cosman RFG-1A) and needle-electrode system used.

Lesions

With our needle electrode system, permanent lesions can usually be achieved at a tip temperature of greater than 60 °C within 30 seconds. Energy and tip temperature of the active electrode are continuously monitored on the generator and both are gradually increased. During and after the lesioning, motor functions and pain perception and discrimination of hot and cold sensation are tested. Usually, the final lesion is made at 70–80 °C for 60 seconds. If the required level of analgesia is not obtained, the lesion is repeated using the same parameters. We prefer a maximum of three 60-second lesions for unilateral cordotomy. In bilateral cordotomy, we prefer to minimize the number of the lesions, but sometimes use two or three lesions for the dominant pain side [17, 22].

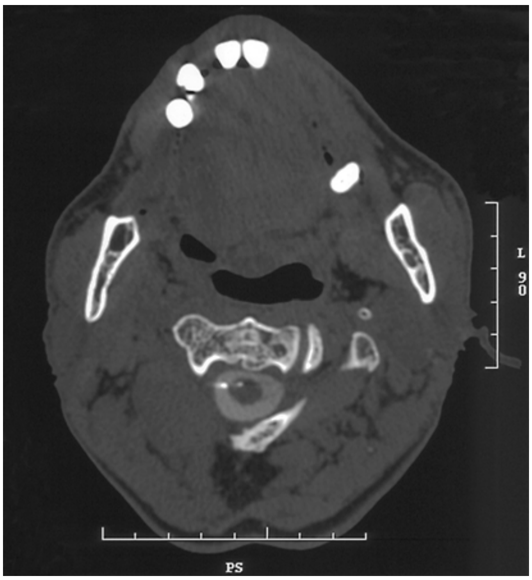

Fig. 5. Final position of the electrode on axial CT scan at the C1–2 level in percutaneous cordotomy

a

b

Fig. 6a and b. The generator (Cosman RFG-1A) (a) and the needle-electrode system used (b)

Postoperative

After the procedure, patients are usually monitored in the intensive care unit (ICU). If the patient's vital parameters are sufficient, the patient can be sent home 5 or 6 hours after the procedure. We usually inform the patient regarding his/her post-cordotomy life. If the patient has special dependency on some narcotic drugs, the doses will be gradually decreased; there is no standard.

Mooij *et al.* have described some causes of failure in high cervical percutaneous cordotomy [33]. In bilateral cordotomy, the patient is usually monitored at least one night in the ICU [23, 27].

Results and complications

Between 1987 and 2006, we performed 232 CT-guided percutaneous cordotomies in 207 patients. Most (193 cases) suffered from intractable pain related to malignancy. In 12 cases, CT-guided cordotomy was performed bilaterally with a one-week interval. In 181 cases, CT-guided cordotomy was performed unilaterally. In the malignancy group, pulmonary malignancies [58], mesothelioma [23] and Pancoast tumors [15] represented the majority of cases (49.7%). In addition, there were 23 patients with gastrointestinal carcinoma, 21 with metastatic carcinoma, and 53 patients with other types of malignancy. The procedure was also applied to 14 cases with benign pain. The initial success rate of CT-guided percutaneous cordotomy was 95%. The success rate was slightly higher in the malignancy group. In the cancer group, only the painful region of the body was relieved from pain in 83%, thus achieving selective cordotomy. In 12 cases, bilateral selective percutaneous cordotomy was successfully applied [22–27]. Due to respiratory complication risks, 12 bilateral cordotomies were performed in cases of pain only below the chest region. Nevertheless, in bilateral cordotomy Ondine's curse may be a problem. However, the appearance of arrest of nightly breathing (Ondine's curse) is dramatically minimized if between the first and the second side a time lag of one week to ten days is left.

Nowadays, percutaneous cordotomy is often referred to as an old and ablative technique and is usually criticized regarding its success rate, complications and failures. Even in the age of science and technology, based on my own experience I can confirm that cordotomy with CT guidance is a safe and effective method for selected intractable pain patients. After performing more than 300 CT-guided procedures, we can report no mortality and major complications. In 207 percutaneous cordotomy series, there was no mortality or major morbidity. We observed only five cases (2.4%) of temporary motor

Table 2

Patients in Cordotomy (Total: 207)
Pulmonary malignancies (58)
Mesotheliama (23)
Pancoast tumor (15)
Gastrointestinal carcinoma (23)
Metastatic carcinoma (21)
The other malignancies (53)
Benign pain (14)

Table 3

Complications
Mortality (0%)
Major morbidity (0%)
Temporary motor complication (2.4%)
Temporary ataxia (2.4%)
Hypotension (1.4%)
Temporary urinary retention (0.9%)
Dysesthesia (1.9%)

complication and five cases of temporary ataxia. These complications usually resolved within three weeks. In the bilateral cordotomy series, there were three cases (1.4%) of temporary hypotension and two cases (0.9%) of temporary urinary retention; these also returned to normal. The only true complication post-cordotomy in our series was dysesthesia, seen in four cases (1.9%).

The numbers of the patients and complications have been presented in Tables 2 and 3.

CT-Guided trigeminal tractotomy-nucleotomy (TR-NC)

Destruction of the descending trigeminal tract in the medulla is known as trigeminal tractotomy. The procedure was first performed in 1938 by Sjöqvist [45]. In 1969, Sweet observed hypoalgesia in the regions innervated by the 7th, 9th, and 10th cranial nerves after trigeminal tractotomy [49]. In 1965, Kunc developed a high cervical approach for cutting the tractus and used the procedure selectively to relieve glossopharyngeal neuralgia, with a high rate of success [28]. Crue *et al.* and Hitchcock independently developed a stereotactic percutaneous technique using RF thermocoagulation that enabled them to perform the first stereotactic trigeminal tractotomies [4, 13]. Schvarcz used this technique and named 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 [43]. In 1990, Nashold *et al.* described an open surgical technique to destroy the whole substantia gelatinosa of the nucleus caudalis and named the procedure nucleus caudalis DREZ operation [36, 37]. We adapted the CT-guided system to the trigeminal tractotomy in 1989, terming it CT-guided trigeminal tractotomy-nucleotomy (TR-NC) [19, 21], and have routinely performed the procedure since that time.

Anatomic target

The main anatomic target is the lateral descending trigeminal tractus located in the posterolateral part of the spinal cord. Anatomical details of the pain con-

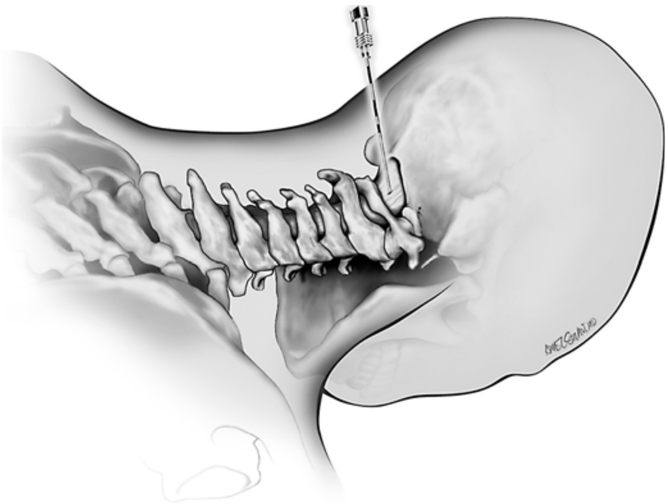

Fig. 7. Schematic drawing of percutaneous TR-NC approach at occiput-C1 level

ducting tractus and especially of the descending trigeminal tractus and nucleus caudalis have been presented by us in several papers [23–26]. This target is approached at the occiput-C1 level (Fig. 6). Localization of the target is defined by CT visualization (Fig. 7). As stated previously, diametral measurements of the spinal cord are taken for each patient before the procedure and calibration of the inserted part of the active electrode is obtained with the help of these measurements.

Indications and contraindications

Trigeminal TR-NC operation is principally based on the lesioning of the descending trigeminal tractus and nucleus caudalis, which carry pain and temperature sensation fibers of the face, ear and throat. Pertinent anatomy and physiology of the system have been described in previously published papers. These targets are optimum sites for lesioning of the tractus and nucleus. The best candidates for the procedure are patients with unilateral localized intractable central and peripheral 5th, 7th, 9th, and 10th painful areas of the face, ear and throat. In this group, those appropriate for treatment with trigeminal TR-NC operation include patients with anesthesia dolorosa, post-herpetic dysesthesia, atypical facial pain, dysesthetic squeal after previous trigeminal surgery, post-traumatic neuropathy, and head, neck or facial pain due to malignancy, and those with vagal, glossopharyngeal or geniculate neuralgia [19, 21, 24–26]. Occipitocervical bone abnormalities would preclude application of the procedure, but this has not been encountered in our limited practice. Patients with short neck and highly obese patients are also not suitable for TR-NC.

Technique

Preparation of the patient

Preparation of the patient is similar to the preparation for percutaneous cordotomy.

Positioning

CT-guided TR-NC is performed in the CT unit. After the administration of contrast material, the patient is taken to the CT unit and placed on the CT table in the prone position [24–26]; the head is positioned on the headrest, slightly flexed and fixed with band. The chest is elevated and supported with soft pads. A nasal catheter is placed to provide oxygen during the procedure [24–26].

Anatomic localization with CT

Before each procedure, routine cranial CT scan is obtained. Routine lateral scanogram and axial CT slices of the occiput-C1 level are obtained. Diametral measurements of the spinal cord are taken, and distance between skin and dura is measured at the occiput-C1 level. A 20 or 22 gauge cannula is preferred following injection of the local anesthetic agents; the cannula is inserted at the occiput-C1 level via posterior parasagittal route, 7–8 mm lateral from the midline. Placement of the cannula at the occiput-C1 level can be visualized in the lateral scanogram and the direction of the needle can be manipulated toward the occipitocervical space with the help of axial CT sections (Fig. 8). The needle

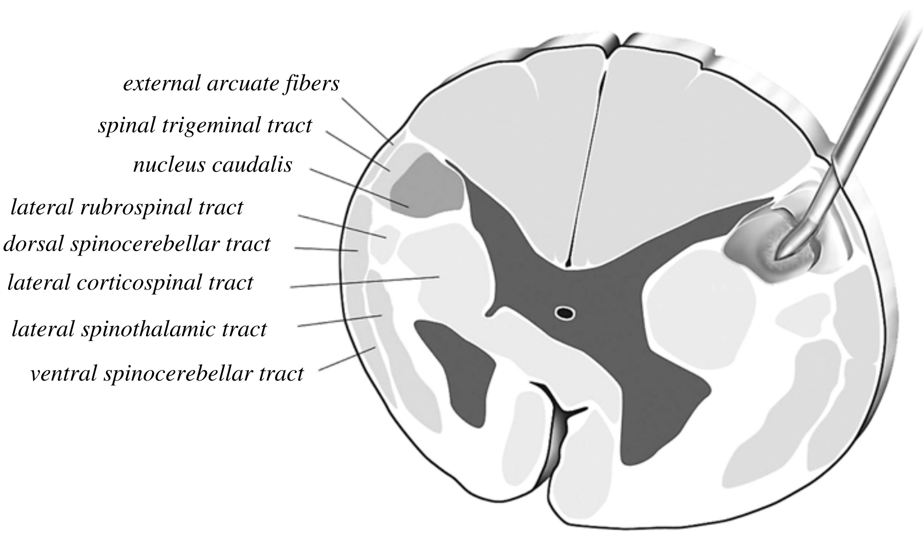

Fig. 8. Schematic drawing of the target-electrode relation and main anatomical structures in percutaneous TR-NC

is positioned posterolaterally to the spinal cord (Fig. 9). The best place for the electrode tip is toward the lateral third of the transverse diameter (equator) of the semi-cord (Fig. 10). After achieving the ideal position of the needle tip, the straight or curved electrode is inserted [24–26]. Curved electrode provides a 1 mm more anterior, posterior and lateral, medial extensions in the area.

Fig. 9. Lateral radiograph of TR-NC

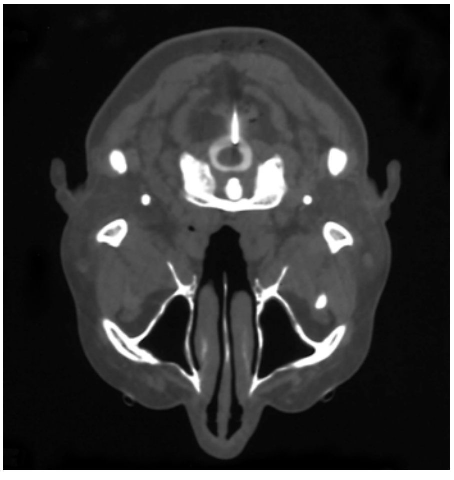

Fig. 10. Final position of the cannula on axial CT scan at occiput-C1 level in TR-NC

Physiologic localization

With the help of neurophysiological confirmation via impedance measurement and stimulation, functional response of the target is confirmed. Impedance measurements are taken to identify whether the active electrode tip is in the CSF (around 100 Ω), in contact with the spinal cord (around 300 or 400 Ω) or inside the spinal cord (more than 700 Ω). The target-electrode relationships are easily detected by direct visualization of the needle-electrode system by CT-guidance [24–26]. Puncture of the tractus nucleus complex is painful. The patient must be informed in this regard and a neuroleptic anesthetic is mandatory before the insertion. Electrical stimulation with low (2–5 Hz, 0.3–0.5 V) and high (50–100 Hz, 0.2–0.3 V) frequencies is used. Paresthesia of the ipsilateral half of the face can be observed with stimulation in most patients. Geniculate, glossopharyngeal and vagal fibers are usually located posterolaterally to the targets and the patient describes some dysesthetic sensation in the throat or inside the ear, indicating that the tip is in the nociceptive fibers of the 7th and 10th cranial nerves [24–26].

Lesions

With our needle electrode system, permanent lesions can usually be achieved at a tip temperature of greater than 40–45 °C within 10–20 seconds. Lesioning of the tractus nucleus complex is painful. Energy and tip temperature of the active electrode are continuously monitored on the generator and both are gradually increased. Some patients cannot tolerate high temperatures around 70 °C. If the patient tolerates 65–70 °C, two or three lesions are performed. Each lesion is of 60 seconds duration [19, 21, 24–26].

Postoperative

After the procedure, patients are usually monitored in the ICU. If the patient's vital parameters are sufficient, the patient can be sent home 5 or 6 hours after the procedure. We usually inform the patient regarding his/her post-TR-NC life. If the patient has special dependency on some narcotic drugs, the dose will gradually be decreased; there is no standard [24–26].

Results and complications

Between 1987 and 2006, we performed 65 CT-guided trigeminal TR-NC in 61 patients. Complete or partial satisfactory pain control was obtained in 52 patients (88.1%). The first and largest group consisted of 19 patients with atypical facial pain. Total or partial pain control was obtained in 17 patients; in the remaining two, nucleus caudalis DREZ operation was partially effective.

Good results were obtained from the group with glossopharyngeal (n: 16) or geniculate (n: 4) neuralgia. In the glossopharyngeal group, pain control was obtained partially or completely in 14 of the 16 cases. In this group, a small lesion was effective. In two cases, the procedure was ineffective. Recurrence was seen in six cases – in two repeated tractotomy, in two additional rhizotomies and in the last two nucleus caudalis DREZ operation controlled the pain attacks. In the geniculate group, we treated four patients with TR-NC. In three of them, the procedure was effective, and in one TR-NC did not control the pain attack. We performed nucleus caudalis DREZ operation. The pain was controlled but the patient died because of severe pulmonary edema on the postoperative 2nd day.

The third largest group consisted of 12 patients with craniofacial and oral cancer pain. In this group, 11 of 12 patients were successfully treated by TR-NC. In one case, pain relief was not complete and in one invasive hypophisial tumor, the pain was not controlled. For these two patients, nucleus caudalis DREZ operation was used but pain control was obtained in only one.

In unilateral post-herpetic neuralgia of the craniofacial region, four cases were treated with TR-NC; in two cases, pain control was obtained, and in one case, nucleus caudalis DREZ was performed but neuropathic pain was not completely controlled. No further treatment was attempted in the fourth case.

Two cases of multi-operated trigeminal neuralgia and one of bilateral trigeminal neuralgia were treated with nucleus caudalis DREZ operation. The procedure was partially effective in all of them.

There was no mortality in CT-guided TR-NC; only six cases (approximately 10%) of transient ataxia were observed. Transient motor complication was observed in two cases at a rate of approximately 3%. All of these complications disappeared in two weeks.

CT-Guided extralemniscal myelotomy

Extralemniscal myelotomy is a stereotactic lesioning of the central cord at the cervical medullary junction. The procedure was first performed by Hitchcock in 1968 to destroy the upper cervical commissural fibers and attain analgesia in a patient suffering from pain in his neck and both arms caused by esophageal adenocarcinoma [12]. Later procedures on the central cord show that the lesions caused relief of pain not only in the upper body and extremities but also in the lower body and extremities, as well as relief of visceral cancer pain. In 1976, Schvarcz 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" [42]. He named the procedure "extralemniscal myelotomy". Gildenberg and Hirshberg performed limited myelotomy with an open technique at the T-10 level for similar purposes [8, 11]. Nauta *et al.* used central cord lesioning by an open method at the T-7 and T-4 levels using a punctate incision with a 16-gauge needle [11]. In the past, percutaneous extralemniscal myelotomy has conventionally been performed with the aid of radiographic visualization at the occiput-C1 level, although we have recommended later using CT-guided technique since 1988. In 1997, Nauta *et al.* reported punctate midline myelotomy for destruction of midline dorsal column visceral pathway as demonstrated by Hirshberg *et al.* [8, 11]. The same procedure was repeated by Becker *et al.* for visceral cancer pain [1]. All of these procedures were performed in the central cord region percutaneously or via open procedure.

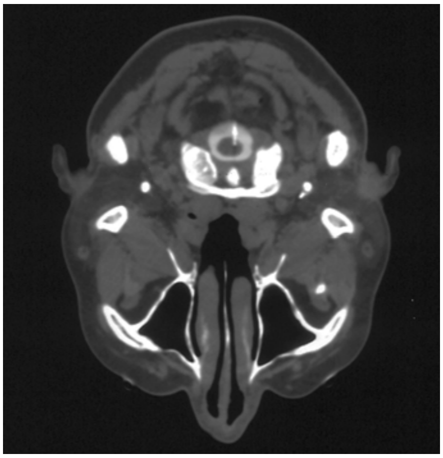

Fig. 11. Final position of the electrode on axial CT scan at occiput-C1 level in TR-NC

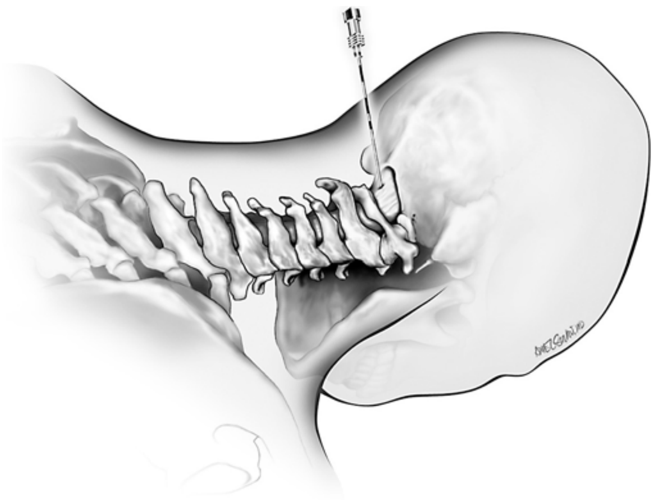

Fig. 12. Schematic drawing of percutaneous extralemniscal myelotomy approach at occiput-C1 level

Since 1986, we have used CT guidance for stereotactic upper cervical central cord lesioning and have named the procedure stereotactic extralemniscal myelotomy [15, 20].

Anatomic target

The main anatomic target is in the central part of the spinal cord. Anatomical details of the central spinal cord and ascending multi-synaptic pathway have been presented by us in many papers [24–26]. This target is approached at the occiput-C1 level (Fig. 11). Localization of the target is defined by CT visualization (Fig. 12). Diametral measurements of the spinal cord are taken for each patient before the procedure and calibration of the inserted part of the active electrode is obtained with the help of these measurements.

Indications and contraindications

CT-guided extralemniscal myelotomy operation is principally based on the lesioning of the central cord area at the occiput-C1 level [24–26]. The mechanism of the procedure is not properly known. In my limited experience, the best candidates for the procedure are those with visceral chronic cancer pain of lower abdominal and perianal regions [24–26].

Technique

Preparation of the patient

Preparation of the patient is similar to the preparation for percutaneous cordotomy.

Positioning

CT-guided extralemniscal myelotomy is performed in the CT unit. After the administration of contrast material, the patient is taken to the CT unit and placed on the CT table in the prone position; the head is positioned on the headrest, slightly flexed and fixed with band. The chest is elevated and supported with soft pads. A nasal catheter is placed to provide oxygen during the procedure [24–26].

Anatomic localization with CT

Before each procedure, routine cranial CT scan is obtained. Routine lateral scanogram and axial CT slices of occiput-C1 level are obtained. Diametral measurements of the spinal cord are taken, and distance between skin and dura is measured at occiput-C1 level. A 20 or 22 gauge cannula is preferred following

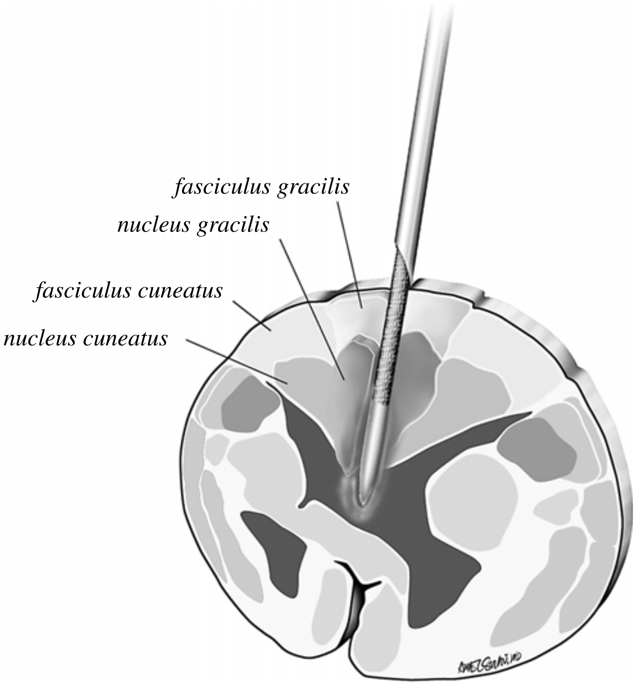

Fig. 13. Schematic drawing of the target-electrode relation and main anatomical structures in percutaneous extralemniscal myelotomy

injection of the local anesthetic agents; the cannula is inserted at the occiput-C1 level, posterior parasagittal route at the midline. Placement of the cannula at the occiput-C1 level can be seen in the lateral scanogram and the direction of the needle can be manipulated towards the occipitocervical space with the help of axial CT sections (Figs. 13–15). The needle is positioned at the posterior midline of the spinal cord at the occipitocervical level. The best position for the electrode tip is the medial part of the occipitocervical junction of the spinal cord. After localization of the cannula at the posterior part of spinal cord at the occipitocervical junction, the active straight electrode is inserted to the midline [24–26].

Physiologic localization

With the help of neurophysiological confirmation via impedance measurement and stimulation, functional response of the target is confirmed. Impedance measurements are taken to identify whether the active electrode tip is in the CSF (around 100 Ω), in contact with the spinal cord (around 300 or 400 Ω) or inside the spinal cord (more than 700 Ω). The target-electrode relationships are easily detected by direct visualization of the needle-electrode system by CT-guidance [24–26]. Puncture of the posterior part of the spinal

Fig. 14. Lateral radiograph of extralemniscal myelotomy at occiput-C1 level

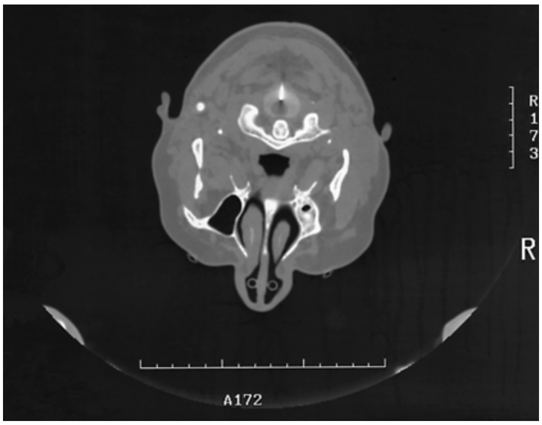

Fig. 15. Final position of the cannula on axial CT scan at occiput-C1 level in extra-lemniscal myelotomy

cord in the midline is not painful. Electrical stimulation with low (2–5 Hz, 0.3–0.5 V) and high (50–100 Hz, 0.2–0.3 V) frequencies is used. Paresthesia of bilateral lower extremities indicates that the electrode is in the proper target [24–26].

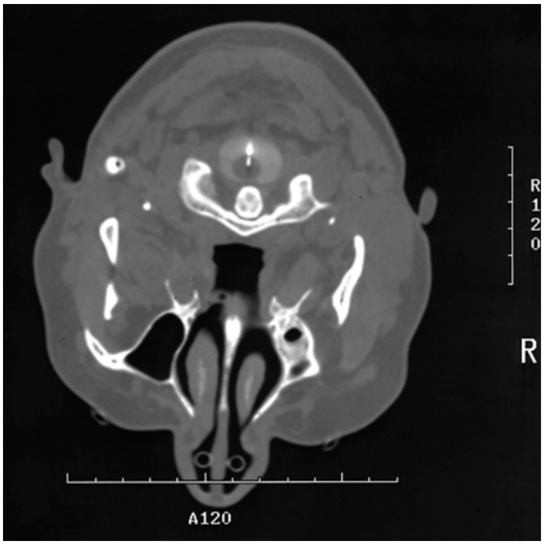

Fig. 16. Final position of the electrode on axial CT scan at occiput-C1 level in extralemniscal myelotomy

Lesions

With our needle electrode system, permanent lesions can usually be achieved at a tip temperature of greater than 60 °C within 30 seconds. Lesioning of the central cord is not painful. Energy and tip temperature of the active electrode are continuously monitored on the generator and both are gradually increased. Two or three lesions can be performed around 70–80 °C to the same location [24–26].

Postoperative

After the procedure, the patient is usually monitored in the ICU. If the patient's vital parameters are sufficient, the patient is sent home 5 or 6 hours after the procedure [24–26].

Results and complications

Between the years 1987 and 2006, we treated 16 cases with CT-guided extralemniscal myelotomy. Complete or partial satisfactory pain control was obtained in 11 cases. In five cases, no contribution to pain status was obtained. We are not aware of the mechanism of the lesioning of the central cord and for this reason can offer no special comment about this procedure and its results. No particular complication or mortality was seen.

Conclusions

Destructive pain surgery is usually applied using stereotactic localization principals. Stereotactic principals and proper localization are needed for morphological target. Morphological localization was not properly obtained in the past, but given the scientific advances in the last two decades, application of direct visualization systems (like CT or magnetic resonance imaging, MRI) have become routine for safe application [5, 15, 17, 19, 31]. The second step of the procedure is physiological localization, which indicates which anatomical structure locates in the target area. This localization is properly obtained using impedance measurements and stimulation. Impedance measurement only provides information about the tissues, but stimulation reveals the function of the target where the tip of the active electrode is located. Another difference in stereotactic destructive pain procedures is the possibility it provides to observe neurological functions of the patient during the procedures. This interactive observation serves as a guide to the surgeon throughout the procedure. In other words, if the surgeon's experience and knowledge about the morphology of the system are adequate and if the physiological evaluation of the target is observed by him/her, the procedures are applied safely and effectively. Despite these great advantages, such procedures have nearly disappeared in current neurosurgical practice. As mentioned previously, despite the availability of new drugs and pump and stimulation techniques, the use of destructive pain procedures is still an option in neurosurgical practice. Aside from their safety and efficacy, their most important advantage is that routine visits to the hospital or doctors for refilling or calibration of systems are no longer necessary. These independent patients are sometimes able to return to their normal life if the primary disease is under control. The other advantage of this destructive procedure is that it is much cheaper than paying for pump or a stimulator. For these reasons, these procedures should be learned by specialist neurosurgeon and must be criticized and evaluated by experienced scientists.

The most important procedure of this group is the cordotomy. Before the CT and MRI era, some criticism of the cordotomy as a destructive method was justified, but given the technological advances, the mortality risk today is nearly zero. We must refer to the procedures mentioned herein as minimally invasive as well. Cordotomy is the best method for controlling unilaterally localized chronic cancer pain states. There is no comparable alternative to it. From among the works of the last two decades, there have been very few large series about percutaneous cordotomy. Two important collected series were published by Lorenz and Sindou [30, 44]. They stated that cordotomy is an effective procedure, but carries high risk of mortality and morbidity, at 0–9%. In bilateral cordotomy, mortality rates increase dramatically, up to 50%. However, these mortality rates are given for the X-ray guided percutaneous cordotomy group [5, 26, 31, 39, 51]. These complications significantly drop, to nearly 0%, with CT guidance. In the very important work of Lahuerta *et al.* [29], it was reported that approximately 20% of the cord must be destroyed to achieve adequate pain relief. This is a very important point related with the efficiency and complications of percutaneous cordotomy. The most important part of this procedure is anatomically localizing how we approach this 20% of the spinal cord with a real-time, direct, morphologically-based visualization system in place of X-ray visualization. As stated before, the first step of the procedure is anatomical localization, the second must be neurostimulation, and the procedure is finalized with controlled lesioning [24]. Sindou criticized the procedure, citing diminished hypo-analgesia level and percentage of pain relief over time [44]. However, if pain recurs, it is easy to re-operate when necessary with the help of CT-guidance. In our series, in the case of five patients, even though their pain scores were satisfactory, they insisted on repeat cordotomy for the comfort it provided. This is perhaps one of the strongest testimonies to the value of the procedure.

The second procedure in this group (TR-NC) is unique, because with localization of only the 5th, 7th, 9th, and 10th pain fibers in the descending trigeminal tractus and nucleus caudalis; it is possible to denervate these pain nerve areas. In the practice of craniofacial cancer pain treatments, it is not easy to denervate the painful areas of the 5th, 7th, 9th, and 10th nerves. The descending trigeminal tractus and nucleus caudalis are the only targets that enable us to denervate painful areas of these nerves percutaneously [24–27]. This procedure is the exact alternative to nucleus caudalis DREZ operation as a first step in treatment of craniofacial or cranio-oral carcinogenic chronic pain states. In this group, because of the invasion of many cranial nerves, it is not feasible to approach each nerve separately and perform pain procedures. However, TR-NC makes possible the effective and easy control of these symptoms. If we compare the risk of the procedures, ataxia risk was limited and the mortality rate was 0% in our 65 procedures. One of the patients in this group also insisted on reapplication of the procedure despite satisfactory pain scores.

We do not have sufficient knowledge and experience about central cord lesioning, but I believe that the central cord area is an important target area for visceral cancer pain. In the near future, after gaining an understanding of real functions of visceral ascending systems, these procedures will be standardized and widely used in neurosurgical practice. Finally, I believe destructive pain procedures are highly effective in controlling some special intractable chronic cancer pain. These procedures must be performed by the neurosurgeon and must be popularized in view of their safety and effectiveness.

Acknowledgement

This work was partly supported by the Turkish Academy of Sciences. I express my gratitude to Mrs. Mukaddes Kurum Yucel for her assistance in writing the manuscript, Mrs. Corinne Logue Can for her language editing, and Dr. Ahmet Sinav for his creative illustrations. This paper is dedicated to the memories of Dr. Murat Rezaki and Dr. Gunfer Gurer Aydin.

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