Peripheral Nerve Stimulation: Fluoroscopic Implant Techniques

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Abbreviations

CT	computed tomography
IPG	implanted pulse generator
ONS	occipital nerve stimulation
PNFS	peripheral nerve field stimulation
PNS	peripheral nerve stimulation

Introduction

Following the original work by Wall and Sweet in 1967 demonstrating the efficacy of peripheral nerve stimulation (PNS), the early PNS devices consisted of a paddle electrode placed along the nerve which necessitated open surgical dissection/exposure and thus restricted the procedure to orthopedic, plastic, and neurological surgeons specializing in peripheral nerve surgery [1, 2]. In 1999, the first description of a percutaneous implantation technique for occipital nerve stimulation (ONS) completely revolutionized the field, opening the door for implantation to nonsurgical specialists while also expanding indications and reducing the invasive nature of the procedure [2, 3]. As opposed to open dissection and neurolysis, emphasis shifted toward reliance on anatomical landmarks and imaging such as fluoroscopy and/or

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ultrasound for percutaneous implantation. The application of percutaneous techniques has evolved to include stimulation of various somatic nerves, including trigeminal branches and peripheral nerves of the trunk and extremities [4]. This technique has gained in popularity due to its low invasiveness and technical ease, obviating the need for open surgical dissection and nerve exposure [5].

When percutaneous technique is used, the trial electrodes are often discarded upon trial completion, therefore requiring insertion of new electrodes during the second stage of the PNS procedure, the so-called permanent implantation. In this scenario, reliance is placed on standard anatomical landmarks based on limited variability in the nerve course and an ability to capture the nerve with multiple contacts of the stimulating electrode. In addition, both fluoroscopy and ultrasound are useful intraoperatively to check the direction of electrode path and the position of the targeted nerve, respectively [5]. While fluoroscopy is useful in visualizing lead location in relation to bony anatomical landmarks, it does not visualize nerves and blood vessels. Thus, other means of image guidance, such as ultrasound, serve as a useful adjunct to ensure optimal electrode positioning and help to avoid nearby vessels [6]. This chapter will focus specifically on the use of intraoperative fluoroscopy to guide and confirm the placement of percutaneous PNS electrodes.

Fluoroscopically Guided Procedures and Workflow

The general workflow to fluoroscopic lead placement for both PNS and peripheral nerve/field stimulation (PNFS) has been previously described [7] and is detailed below.

The patient is positioned to allow for optimal access to the region of interest. Careful consideration should be made to allow for optimal fluoroscopic access and image acquisition of the target site. Performing the procedure under conscious sedation provides adequate patient comfort and anxiolysis during electrode placement while also allowing for intraoperative confirmation of acceptable paresthesia coverage described by the patient. Perioperative antibiotics are administered, and standard surgical preparation and draping are performed with the entire planned path of the electrode visible within the sterile surgical field. The general workflow for a percutaneous PNS lead placement trial is then performed via the following sequential steps:

1. After infiltration of the entry point with local anesthetic, a small stab incision is made.
2. A straight or slightly curved Tuohy needle is slowly advanced into the subcutaneous space overlying the nerve. The trajectory of the needle may be in parallel to the target nerve or at an angle. PNFS electrodes are arranged variably to provide optimal coverage of the entire painful area.
3. The inner stylet of the Tuohy needle is withdrawn, and the electrode lead is threaded through the needle and its position is confirmed with fluoroscopy.
4. The Tuohy needle is then removed leaving the electrode lead in place.

5. The electrode lead is connected to a temporary testing cable. The patient's sedation is lightened so that any perceived paresthesias are reported. The optimal stimulation coverage can be ascertained by changing the combination of anode and cathode contacts and varying amplitude, frequency, and pulse width. If these alterations do not result in optimal coverage of the target area, then the electrode can be repositioned.
6. After optimal electrode position is confirmed, it is secured at the entry site with a single stitch. The site is further dressed with a sterile occlusive dressing. The externalized trial electrode is then connected to the trial stimulator system. Fluoroscopic images or plain radiographs should be obtained to document final electrode position.
7. These steps are repeated for each additional electrode planned. For most PNS cases, 1 or 2 electrodes are used. For PNFS, multiple electrodes may be needed to provide adequate coverage.

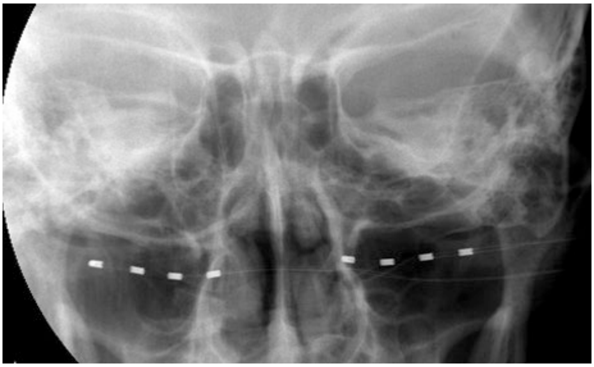
The specific types of PNS stimulation for which fluoroscopic implantation techniques are utilized are described below.

Occipital Nerve Stimulation

The electrodes are generally implanted perpendicular to the course of the greater occipital nerves on one or both sides of the patient's head at the level of craniovertebral junction [5]. The direction of insertion and the anchoring points vary among those who perform the procedure. The senior author prefers to anchor the occipital PNS electrodes in the retromastoid region while tunneling them toward the implanted pulse generator (IPG) located in the infraclavicular region [8]. A thorough description of the procedure by the senior author has been previously described in detail [9]. For permanent device and bilateral lead implantation, the patient is placed supine with the head turned maximally away from the infraclavicular side chosen for IPG insertion. The head is positioned on a small cushion, allowing access to the dependent occipital region and mastoid process. The occipital area, neck, and upper chest on the ipsilateral side are prepped and draped in the usual sterile fashion. The C-arm fluoroscopy machine is oriented perpendicularly around the patient's head, such that sufficient space allows for the implanter to stand within the C-arm during implantation (Fig. 1). For lead implantation, a 2.5 cm straight, vertically oriented retromastoid incision is made to the fascia, and the tissues medial and lateral are undermined in order to create an anchoring pocket and to allow for creation of a strain relief loop. Next, a stab incision is made in the midline at the level of C1 for percutaneous placement of the contralateral electrode. The inserting needle is advanced toward the contralateral mastoid process under fluoroscopic guidance. For the ipsilateral side, the inserting needle is advanced through the ipsilateral retromastoid incision toward to the midline within the epifascial plane under fluoroscopic guidance. The stylets are removed and the electrodes are inserted through each

Fig. 1 Patient and C-arm fluoroscopy positioning for ONS electrode implantation

Fig. 2 Intraoperative fluoroscopic image confirming adequate placement of bilateral ONS electrodes



needle, again under fluoroscopic guidance with the ipsilateral electrode traveling from retromastoid incision toward midline and the contralateral electrode traveling from midline to contralateral mastoid process. The leads are tunneled subcutaneously using the same insertion needles with the stylets removed and are anchored within the retromastoid incision with strain relief loops next to each anchor. These leads are then subcutaneously tunneled to an infraclavicular pocket made for the IPG. Final fluoroscopic images are taken to ensure that the placement of the leads remains adequate after tunneling (Fig. 2).

Trigeminal Branch Stimulation

Percutaneous techniques for trigeminal branch stimulation (supraorbital, supratrochlear, infraorbital, auriculotemporal, and, most recently, the mental and inferior alveolar branches of the mandibular nerve) are technically similar to occipital PNS. Electrodes are placed based on anatomical landmarks crossing the course of

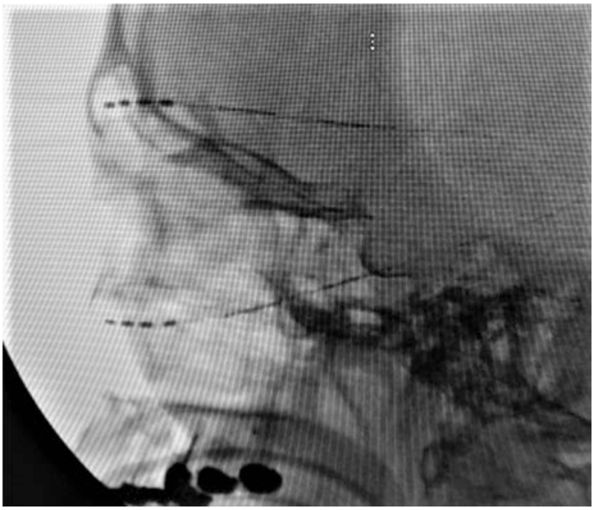


Fig. 3 Intraoperative fluoroscopic image confirming adequate placement of trigeminal branch electrodes

the targeted nerve(s) [5]. A stab incision is made over the zygoma at the temporal pre-auricular hairline, and a contoured 12- to 14-gauge Tuohy needle is advanced within the epifascial plane toward the painful region. Once the needle tip is in place, a four or eight contact electrode is advanced through it all the way to the target under fluoroscopic guidance [10]. Typical landmarks used for fluoroscopic guidance include the supraorbital groove/foramen, the infraorbital foramen, the floor of the orbit, etc. [10, 11]. It is crucial that the electrodes are advanced within the epifascial plane which provides sufficient depth to avoid electrode erosion postoperatively. The anchoring point for these electrodes is usually placed in the retroauricular region, and, from there, the electrode or extension cable is tunneled toward the infraclavicular IPG [5]. Final lead location is confirmed with intraoperative fluoroscopy (Fig. 3).

Trigeminal Ganglion Stimulation

Percutaneous lead implantation into the Gasserian ganglion for treatment of intractable neuropathic facial pain has been previously described by the Belgian group of Van Buyten and colleagues using three-dimensional (3D) fluoroscopic techniques [12, 13]. Their technique utilizes an intraoperative three-dimensional computed tomography (3D CT) scan using the O-arm®-coupled electromagnetic neuronavigational system (Axiem, Medtronic) in order to guide electrode placement into the foramen ovale. In the operating room, the patient is first positioned supine on a radiolucent Table. A 3D CT scan using O-arm® is then performed. The obtained images are used to calculate the trajectory to the Gasserian ganglion through the foramen ovale. A small stab incision is made lateral to the labial commissure, and a 15-gauge needle, guided by 3D real-time electromagnetic tip tracking, is inserted into the foramen ovale. Under continuous fluoroscopy, the electrode is inserted until its tip reaches the clivus. Once the electrode contacts reach the target, the patient is awakened, and test stimulation is performed until the patient endorses paresthesia within the area of neuropathic facial pain. The needle is then withdrawn under continuous fluoroscopy so as to assure that the electrode remains in place, and a suture is placed on the electrode at the entry site. No anchor is used. The patient is then re-sedated and the electrode is tunneled subcutaneously between the maxilla and mandibular region [12].

Peripheral Nerve Field Stimulation

PNFS involves the targeting of small distal branches of peripheral nerves within the subcutaneous space by placing one or more electrodes into the region of maximal pain [7, 14]. Field stimulation produces paresthesias within diffuse painful areas that may not necessarily correlate with a single dermatome or is otherwise poorly defined dermatomally. Thus, body regions rather than nerves are used to describe the location of PNFS (i.e., low back, trunk, joint). The technique was outlined by the Australian implanters Verrills and Russo [15].

Octopolar leads are placed subcutaneously within the area of maximal pain using a 14-gauge vascular access catheter under live C-arm fluoroscopy. The ideal depth for the placement of the electrode that provides optimal stimulation of the affected nerves is not well defined between specific patients. More superficial implantation into the dermal layers can result in painful stimulation, while deeper subfascial placement can result in muscle recruitment and uncomfortable sensations [15]. A previously described "pin-drop" technique uses a device with multiple freely moving pins that sits directly on the skin above the desired implantation site. Using fluoroscopic imaging at 30° cephalad and caudad, the depth of each lead can be estimated by measuring the distance between the contacts and the reference pins. Using this technique in 17 patients, its Australian inventors found that the distribution of electrode depth providing adequate stimulation ranged between 4 and 19 mm, with an average depth of 10.5 mm [15]. Once the leads are determined to be at adequate depth and location, on-table stimulation is performed to determine that paresthesia is felt in the area of pain and that it is comfortable. The leads are then sutured to the skin and dressings applied.

Conclusion

Since the introduction of the percutaneous fluoroscopically guided technique in the late 1990s, the use of percutaneous PNS or PNFS electrodes has steadily increased. Fluoroscopy is a useful intraoperative adjunct to both guide and confirm percutaneously placed electrodes in relation to bony anatomic landmarks. When used alone or in conjunction with other intraoperative image-guidance modalities such as ultrasound, fluoroscopy improves both the safety and efficiency of these procedures.

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