

Dorsal Root Ganglia Radiofrequency Procedures

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Dorsal root ganglia (DRG), which contain the cell bodies of primary afferent neurons transmitting sensory information from the periphery to the central nervous system, play a key role in the pathogenesis of chronic pain syndromes caused by spinal pathology and peripheral nerve injury. Reddish in color, their oval shape is directly proportional to the size of the corresponding nerve root.¹ The evidence supporting a primary role for the DRG in chronic pain states has led to the growing use of treatment directed at dorsal root ganglion. First employed by Rosomoff et al² in 1965 during percutaneous cordotomy, conventional radiofrequency (RF) current creates molecular friction when applied to neural tissue, resulting in high temperatures in the 60°C to 80°C range, and a controlled lesion. More recently, the use of pulsed RF, which purportedly works through the induction of an electromagnetic field and leaves the integrity of the targeted neural tissue functionally intact, has generated intense interest in the pain management community.³ The list of pain conditions that are amenable to interventions directed at DRG has been growing rapidly. Since 1974 multiple authors have described the application of RF lesioning of DRG for chronic pain conditions.⁴⁻¹⁸

Indications

- ◆ Interventional techniques directed at DRG have slowly grown in recent years.
 - As shown in Table 1, conditions amenable to DRG RF procedures include chronic neck pain and cervicogenic headache, radiculopathy, chronic postsurgical pain, postamputation pain, postherpetic neuralgia, complex regional pain syndrome, groin pain, and chronic somatic extremity pain.
- ◆ Procedural contraindications are listed in Table 2.
 - These include needle phobia, psychogenic pain, pregnancy, and bleeding diathesis.

Table 1. *The prevalence of pain conditions amenable to thoracic and/or cervical DRG RF procedures.*

CONDITION	PREVALENCE
Chronic neck pain	20%
Cervicogenic headache	0.5%-2.5%
Cervical radiculopathy	0.1%-0.3%
Postmastectomy pain	25%-50%
Postamputation Stump pain	4000 upper extremity amputations are performed each year in the U.S, with approximately 10%-20% having chronic stump pain.
Postthoracotomy pain	25%-50%
Poststernotomy pain	25%
Postherpetic neuralgia	Incidence of herpes zoster is 0.2%-0.4% (PHN) per year, increasing to 1% in pts > 80 years. About 10% of pts have PHN 1 year after lesions resolve (> 20% in elderly). Approximately 50% of cases involve the thorax and 10% the cervical region.
Complex regional pain syndrome (CRPS)	Approximately 2/3 of CRPS pts have predominance of upper extremity symptoms and 1/3 have lower extremity predominance
Chronic somatic arm pain	10% of computer workers
Chronic thoracic spinal pain	5%-10%
Thoracic radiculopathy	Accounts for approximately 0.5% of herniated discs
Groin pain	5% of athletes; 10%-15% after hernia repair
Lumbar radiculopathy	30%-40% of chronic low back pain cases

Table 2. *Contraindications to DRG interventions.*

- Needle phobia
- Psychogenic pain
- Inability of the patient to understand consent, nature of the procedure
- Arnold Chiari malformation for procedures at upper cervical spine
- Infection
- Anticoagulant therapy or non-aspirin combination anti-platelet therapy
- Pregnancy
- Bleeding diathesis
- Emphysematous pulmonary disorders for thoracic procedures

Clinical Applications

The first published report of percutaneous RF DRG was in 1974 by Uematsu et al,⁴ who described cervical, thoracic, and lumbar RF on 13 patients with chronic neuropathic pain of various etiologies. Despite the conceptual appeal of RF lesioning of the DRG, the authors reported a good or excellent outcome in only 3 patients who received a cervical or thoracic procedure. However, most patients who underwent lumbar procedures reported good pain relief. Patients who experienced good or excellent outcome suffered from both neuropathic and nociceptive pain.

There have been 3 randomized, double-blind studies evaluating conventional RF lesioning of DRG for chronic pain.¹⁰⁻¹² In the earliest study, Van Kleef et al¹⁰ randomized 20 patients with intractable cervicobrachialgia to receive either an RF lesion adjacent to one DRG or a sham lesion following diagnostic nerve root blocks. At their 8-week follow-up visits, 8 of 9 patients in the treatment group had successful outcomes vs. 2 of 11 patients in the sham group. In the RF group, 77% of patients noted a burning sensation in the treated dermatome that spontaneously resolved within 3 weeks and another patient experienced postprocedure hypesthesia. In the second study, Slappendel et al¹¹ randomized 61 patients with cervicobrachialgia diagnosed by CT scans and selective nerve root blocks to receive either cervical DRG RF lesioning at 67° (group I) or 40° C (group II). At their 3-month follow-up visits, both groups experienced significant reductions in VAS pain scores, with no difference noted between groups. In group I, 6 patients experienced temporary neuritis that resolved within 3 months, with 5 cases occurring in group II. Loss of muscle strength was noticed by 2 patients in group I and 1 patient in group II.

In the only placebo-controlled study evaluating RF lesioning of the lumbosacral DRG, Geurts et al.¹² randomized 83 patients with sciatica diagnosed with selective nerve root blocks to receive RF thermocoagulation of the DRG or sham lesioning. Three months post-procedure, no difference in any outcome measure was observed between groups.

The results of randomized studies showing a benefit for RF interventions of the DRG are bolstered extensive anecdotal evidence. In a retrospective chart review by van Kleef et al⁹ conducted in 43 patients with spinal thoracic pain, the authors performed thoracic DRG RF ablation at a single level following diagnostic intercostal nerve blocks. Eight weeks postprocedure, 67% of patients obtained at least moderate pain relief, with 52% reporting relief lasting at least 36 weeks. Fourteen patients experienced transient burning pain in the treated dermatome and 7 developed hypesthesia that resolved within 3 months.

Conventional RF of dorsal root ganglion has been associated with neuroma formation resulting in hyperalgesia, allodynia, and unprovoked dysesthesias. Reflex increases in sympathetic activity and deafferentation pain have also been reported. In view of the high incidence of neurological side effects following conventional RF ablation, the use of pulsed RF has generated intense interest in the past few years.

There are only a few reports published utilizing pulsed RF of the DRG. In the sole placebo-controlled study, Van Zundert and colleagues¹⁸ randomized 23 patients with cervical radiculopathy to receive either pulsed RF or sham lesioning of the DRG. In each case, the affected spinal level was diagnosed with a series of 3 selective nerve root blocks. At their 3-month follow-up, patients in the treatment group reported lower pain scores and greater satisfaction than subjects who received sham lesioning. In an earlier retrospective evaluation, the same group reported outcomes after single-level cervical pulsed RF DRG on 18 patients with chronic neck, head, or arm pain.¹³ The authors reported more than 50% pain reduction in 72% of their patients at 8 weeks. The mean duration of relief was 9.2 months in the 13 patients with positive outcomes. Cohen et al¹⁷ compared pulsed RF of the DRG to pulsed RF of the intercostal nerves and medical management in 49 patients with chronic post-surgical thoracic pain. At 3-month follow-up, 54% of pulsed RF DRG patients continued to have a successful outcome, compared to 20% in the pharmacotherapy group and 7% in the pulsed RF intercostal nerve group patients. Pevzner et al¹⁴ treated 28 patients with lumbar or cervical radiculopathy with pulsed RF DRG. They reported good or excellent pain relief in 50% of the patients after 3 months. However, the number of patients who continued to have positive results declined to 32% at 6 months and 29% after 1 year. In addition to radiculopathy and chronic thoracic pain, pulsed RF of the lower thoracic and upper lumbar DRG has also been advocated as a treatment for groin pain.¹⁹ Table 3 summarizes various studies evaluating RF of the DRG for chronic pain conditions.

Table 3. Summary of studies evaluating RF of the cervical or thoracic DRG for chronic pain conditions.

Author and year	Number & type of patients	Vertebral levels & parameters	Results	Comments
van Kleef, 1996 ¹⁰ Double-blind, placebo-controlled study	20 pts with chronic cervicobrachialgia were randomized to cervical DRG RF or sham Rx.	Pts underwent 1 level cervical DRG RF based on selective nerve blocks.	At 8-week follow-up, 89% of the treatment group had a positive outcome vs. 18% in the placebo group.	Blinding adequacy not assessed. 7 pts in treatment group had burning sensation in treated dermatome subsiding after 3 wks. 1 pt, upper arm hypesthesia.
Slappendel, 1997 ¹¹ Randomized, double-blind study	61 pts with cervicobrachialgia were randomized to cervical DRG RF at 67°C (group 1) or 40°C (group 2).	Pts underwent 1 level cervical DRG RF based on selective nerve blocks.	In group 1 pts, 47% had VAS reduction of > 2 vs. 51% in group 2 @ 3-month f/u. In group 1, mean VAS decreased from 6.7 to 5.0 vs. from 6.3 to 4.4 in group 2.	19% and 17% incidence of neuritis in groups I & 2 pts, respectively. 2 pts in group 1 and 1 in group II had muscle strength loss on treated side.
Haspelslagh, 2006 ¹⁶ Prospective, randomized comparative trial	30 pts with cervicogenic headache rec'd either cervical facet denervation, if unsuccessful, a conventional cervical DRG lesion or greater occipital nerve (GON) block with local anesthetic & steroid.	Cervical DRG RF done at 1 level after selective nerve root blocks. Some of the GON block pts also rec'd TENS.	At 16-week f/u, 67% of cervical facet or DRG RF pts had (+) outcome vs. 53% who had GON block. At 1-year f/u, 53% in facet/DRG group vs. 47% in the GON group had (+) outcome (P=NS).	Only 3 patients underwent cervical DRG RF lesioning. Although all 3 reported reduced VAS pain scores, none had a positive "global perceived effect."
Prushansky, 2006 ¹⁵ Prospective, open-label study	40 pts with whiplash who underwent RF neurotomy. 13 pts underwent both medial branch and C2 DRG ablation.	Up to 3 cervical facet levels treated. Details of RF procedure not given. Only C2 DRG done.	70% of pts reported improvement, 30% to 60% when stringent outcome measures were applied. Follow-up at 1 year.	No association between type of RF procedure and outcome.
Pagura, 1983 ⁶ Prospective, cadaveric & clinical study	28 (of 50) pts with malignant and nonmalignant pain of neuropathic & nociceptive origin.	Pts underwent cervical, cervicothoracic, thoracic & thoracolumbar procedures. Levels Mean, 2.5.	6 pts obtained excellent, 14 good, 3 fair, and 5 poor results.	Mean follow-up, 9.3 months. Results better in lumbosacral region.
Verdie, 1982 ⁵ Retrospective study	80 pts w/malignant & nonmalignant pain of neuropathic & nociceptive origin.	Single level procedures done at lumbar, thoracic & cervical levels	Good outcome in 46% , 19% fair, 35% poor, long-term results n/a.	Article in French.
Nash, 1986 ⁷ Retrospective study	17 pts with cancer and nonmalignant pain, mostly neuropathic.	Multilevel procedures done at lumbar, thoracic, and cervical levels.	7 pts obtained excellent, 4 good, and 6 poor results.	Follow-up range: 6 mos to 4 yrs. 2 patients (+) effects subside. 19% incidence of neuralgic pain. Hypesthesia common, but not noted.
Niv & Chayen, 1992 ⁸ Retrospective study	50 pts with cancer pain.	Multilevel procedures done at lumbar and thoracic levels.	Good results in 62% of pts, fair in 28%.	No long-term follow-up available.
van Kleef, 1995 ⁹ Retrospective study	43 pts with nonmalignant chest pain of spinal origin.	Single-level thoracic procedure after intercostal nerve blocks.	67% obtained > 30% short-term pain relief, 22% pain-free.	At 36-wk f/u, 52% continued to report > 30% pain relief, 11% stayed pain-free.
Uematsu, 1974 ³ Retrospective study	6 of 13 pts with nonmalignant, mostly neuropathic pain.	Mean of 3.8 levels. Temps ranged from 55°C to 75°C. 3 cervical and 3 thoracic DRG procedures done.	Cervical procedures, 1 pt each had excellent, fair & poor results. Thoracic, 1 pt each had excellent, good and fair.	Follow-up ranged from 7 to 12 mos. The 2 pts w/ excellent outcomes had nociceptive pain.
van Zundert, 2003 ¹¹ Retrospective study	18 pts w/ nonmalignant neck, head, arm pain of neuropathic and nociceptive (mostly spinal) origin.	Pts underwent single level cervical DRG pulsed RF based on selective nerve blocks.	8 wks post-Rx, 72% of pts obtained > 50% pain relief.	Mean duration of satisfactory relief was 9.2 months.
Pevzner, 2005 ¹² Prospective case series evaluating pulsed RF	8 (of 28) pts with cervical radiculopathy underwent pulsed RF.	Pts underwent single level cervical DRG pulsed RF at C2 based on radiological imaging and clinical findings.	3 months post-procedure results excellent (7%) or good (43%) in half the pts. At 6-mo and 1-yr f/u, good (32%) or excellent (29%) results persisted.	VAS pain scores declined from a baseline of 8.8 to 4.2 at 3 months, 4.8 at 6 months, and 4.9 at 1-year postprocedure. Article in Hebrew.
Cohen, 2006 ¹⁵ Retrospective study evaluating pulsed RF	49 pts with chronic postsurgical thoracic pain rec'd either pulsed RF of thoracic DRG, pulsed RF of intercostal nerves or pharmacotherapy.	Mean number of thoracic DRG levels treated was 2.6. Pts underwent 4 cycles of Rx.	At 3-month f/u, 54% of the DRG pts had > 50% pain relief vs. 20% who rec'd medical Rx and 7% who got pulsed RF of intercostal n.	The mean duration of successful outcome in the pulsed RF DRG group was 4.7 months vs. 11.5 wks in the intercostal group.

Table 3. Summary of studies evaluating RF of the cervical or thoracic DRG for chronic pain conditions, continued.

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Uematsu, 1974 ⁴ Retrospective study	6 of 13 pts with nonmalignant, mostly neuropathic pain.	Mean of 3.8 levels. Temps ranged from 55°C to 75°C. 3 cervical and 3 thoracic DRG procedures done.	Cervical procedures, 1 pt each had excellent, fair & poor results. Thoracic, 1 pt each had excellent, good and fair.	Follow-up ranged from 7 to 12 mos. The 2 pts w/ excellent outcomes had nociceptive pain.
van Zundert, 2003 ¹³ Retrospective study	18 pts w/ nonmalignant neck, head, arm pain of neuropathic and nociceptive (mostly spinal) origin.	Pts underwent single-level cervical DRG pulsed RF based on selective nerve blocks.	8 wks post-Rx, 72% of pts obtained > 50% pain relief.	Mean duration of satisfactory relief was 9.2 months.
Geurts, 2003 ¹² Double-blind, placebo-controlled study	83 pts with lumbosacral radicular pain.	Pts underwent single-level lumbosacral DRG pulsed RF based on selective nerve blocks. Control pts underwent sham lesioning.	3 months post-procedure, no difference was found between rx and control groups on any outcome measure.	Sensory stimulation threshold of 0.5-0.8 V excessive. Half of the pts In RF group had pain duration > 5 yrs.
Pevzner, 2005 ¹⁴ Prospective case series evaluating pulsed RF	8 (of 28) pts with cervical radiculopathy underwent pulsed RF.	Pts underwent single level cervical DRG pulsed RF at C2 based on radiological imaging and clinical findings.	3 months post-procedure results excellent (7%) or good (43%) in half the pts. At 6-mo and 1-yr f/u, good (32%) or excellent (29%) results persisted.	VAS pain scores declined from a baseline of 8.8 to 4.2 at 3 months, 4.8 at 6 months, and 4.9 at 1-year postprocedure. Article in Hebrew.
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Van Zundert, 2007 ¹⁸ Double-blind, placebo-controlled study.	23 pts with chronic cervical radicular pain.	Pts underwent either single-level pulsed RF or sham lesioning of DRG following selective nerve root blocks. Pts rec'd one cycle of rx.	3-months post-procedure, pts In rx group had greater pain relief and satisfaction than control group.	82% of pulsed RF group and 33% of sham group had (+) outcome.

Pathophysiology

- ◆ Following peripheral nerve injury, ion channel modulation occurs leading to nociceptor sensitization, expansion of receptive fields, diminished central inhibition, increased neuronal excitability in the spinal cord, and reorganization in the dorsal horn.
 - Ion channel alterations that are in part responsible for these effects include proliferation of voltage-dependent sodium channels in the DRG, down regulation of voltage-gated potassium channels, and increased expression of the calcium channel alpha-2 delta-1 subunit.²⁰⁻²³
- ◆ A growing body of literature supports a relationship between peripheral nerve injury and sympathetic sprouting in the DRG.^{24,25}
 - The extent of this sprouting is inversely related to the distance between the injury site and the DRG (i.e. the more proximal the injury site, the greater the proliferation of sympathetic fibers).²⁶
 - Hyperexcitability and ectopic firing occur not only at the site of injury, but also in DRG cell bodies.²⁷
- The end result of these changes is peripheral and central sensitization, manifesting as spontaneous pain, hyperalgesia, and allodynia.
- ◆ Inflammation of the DRG can also be caused by injury or exposure to nucleus pulposus from a herniated disc, leading to the release of trophic molecules and cytokines that play an integral role in the development of pain.²⁸
 - In a study evaluating DRG morphology in 83 subjects with herniated nucleus pulposus, Aota et al²⁹ found MRI evidence of swelling and impingement of the involved DRG, with the severity of symptoms positively correlating with the degree of inflammation and indentation.
 - In an animal model of HNP, Igarashi et al³⁰ found that acute nerve root compression resulted in increased endoneurial fluid pressure and reduced blood flow in the corresponding DRG.
 - Within 24 hours after application of nucleus pulposus, apoptosis occurs at the site of DRG exposure.³¹
 - In rats, COX-2 induction in dorsal root neurons has been demonstrated after peripheral nerve injury, although the clinical implications of this finding are not clear.³²

Anatomy

- ◆ Dorsal root ganglia are large collections of neurons on the dorsal spinal roots.
 - Each is oval and reddish; its size is related to that of its root.¹
 - A ganglion is bifid medially where the 2 fascicles of the dorsal root emerge to enter the cord. Ganglia are usually located in the intervertebral foramina, immediately lateral to the perforation of the dura mater by the roots (Fig. 1).
 - The first and second cervical ganglia lie on the vertebral arches of the atlas and axis, respectively. The sacral ganglia lie inside the vertebral canal, and the coccygeal ganglion usually lies within the dura mater.
 - Small aberrant ganglia sometimes occur around the upper cervical dorsal roots between the spinal ganglia and the spinal cord.
- ◆ Numerous studies have shown wide variation in DRG characteristics throughout cervical, thoracic, and lumbar spinal levels.³³⁻³⁸ These variations relate to the size and shape of the DRG, the origin and take-off angles of the nerve roots, and the position of the ganglia relative to the foramen.
 - In a cadaveric study, Yabuki and Kikuchi,³³ found 48% of C6 DRG and 27% of C7 DRG to be proximally situ-

ated, with the point of delineation being an imaginary line connecting the center of the pedicles. In phase 2 of the study, the authors classified the position of the C6 and C7 DRG in 60 patients with radiculopathy using nerve root infiltration and radiography. At C6, 33% of DRG were proximally located, compared with 50% at C7. No correlation was found between subjective symptoms, MRI diagnosis (i.e., spondylosis or herniated disc), and the positions of the DRG. Of note, nerve root infiltration was found to provide better pain relief in patients in whom DRG were distally situated.

- In another cadaveric study examining C2 DRG, Bilge³⁵ found that 70% were oval-shaped, 20% spindle-like and 10% spherical. The mean height of the C2 ganglion was 5.0 mm on the right side and 4.6 mm on the left.
- *A recent study using 3D fast field echocardiography in conjunction with MR imaging found over 98% of lumbar DRG to be foraminally located, with less than 2% being extra-foraminal.³⁸ No DRG were found to be intraspinal from L1-L4, although 5.7% of L5 DRG were within the spinal canal. The size of the DRGs gradually increased from L1-L5; biganglionic DRG were most commonly found at L3 and L4.*

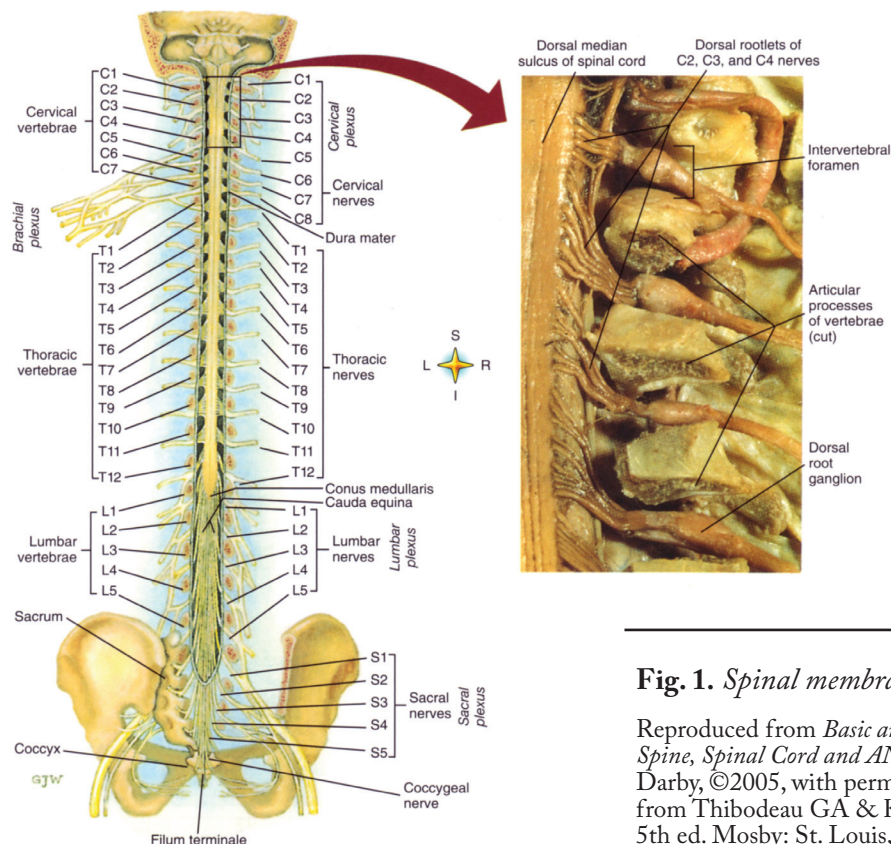


Fig. 1. Spinal membranes and nerve roots.

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Technique

- ◆ Since DRG are not visible using plain radiographs and there is a large degree of variability between patients, DRG may be located by placing the electrode tip in the center of the relevant neural foramen as if performing a transforaminal epidural injection. Subsequently, the DRG may be stimulated with the sensory mode of the RF generator.
 - For cervical DRG procedures, the foramen may be entered tangentially to its posterior wall, opposite the equator. However, above this level veins may be encountered, and below this level the needle may hit the spinal nerve or its accompanying arteries (Fig. 2).³⁹
- ◆ During thoracic DRG procedures, rotate the image intensifier in a cephalo-caudad direction until the vertebral endplates line up and the rib becomes discernable from the transverse process (Fig. 3).
 - Without the benefit of a coaxial view (since the thoracic foramen cannot be visualized clearly as in the cervical region), insert the electrode starting no more than 2 inches from the midline, in a slightly medial-cephalad direction under the transverse process.
 - Using lateral fluoroscopic imaging, the electrode is then incrementally walked into the thoracic foramen (Fig. 4).
 - When the needles are provisionally positioned, sensory testing commences at 50 Hz, with the electrode being moved slightly antero-posteriorly and/or supero-inferiorly until concordant dermatomal stimulation is maximized.¹⁷

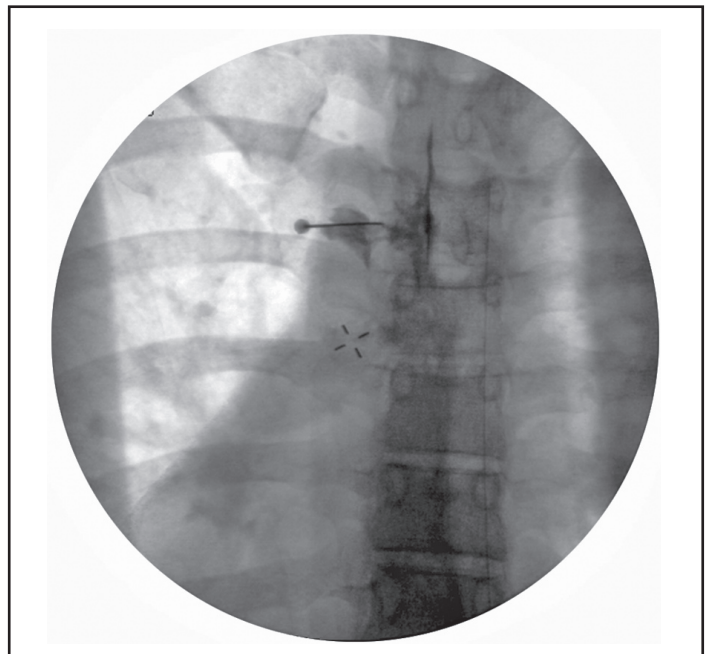


Fig. 3. Antero-posterior fluoroscopic image showing needle placement for thoracic dorsal root ganglion RF procedure. The contrast spread in the vertical direction indicated epidural uptake. Reproduced from Cohen et al.¹⁷ Pulsed RF of the dorsal root ganglia is superior to pharmacotherapy or pulsed RF of the intercostal nerves in the treatment of chronic postsurgical thoracic pain. *Pain Physician* 2006; 9:179-187, with permission from the authors and the American Society of Interventional Pain Physicians.

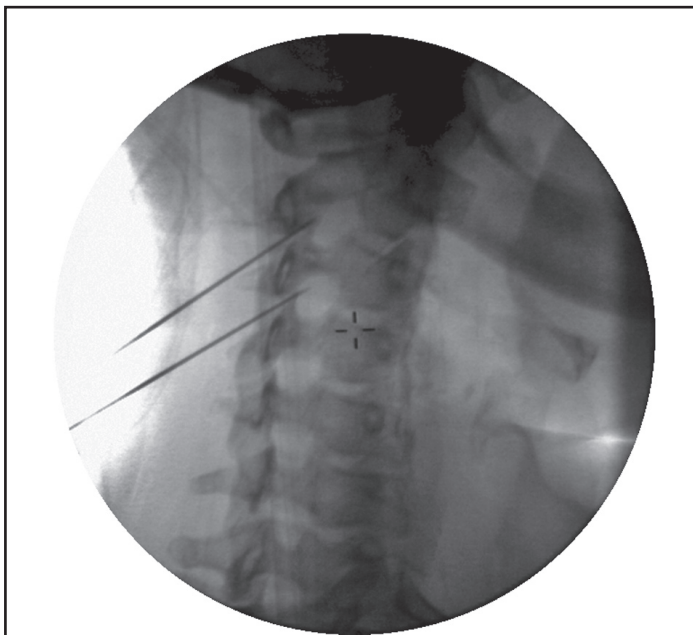


Fig. 2. Oblique fluoroscopic image showing needle placement for cervical dorsal root ganglia pulsed radiofrequency.

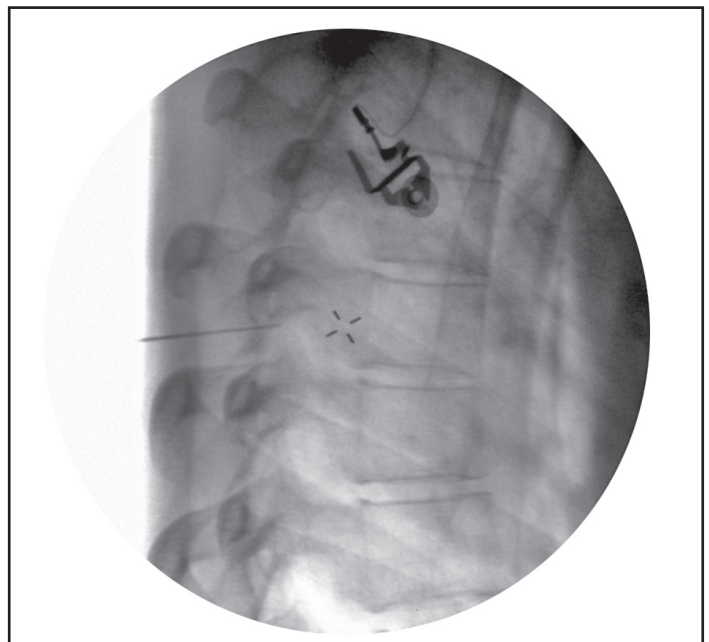


Fig. 4. Muscle movements associated with DRG stimulation.

- ◆ Stimulation usually occurs at 0.1 V, and almost never above 0.2 V (Table 4).
 - Motor stimulation is then performed at a frequency of 2 Hz, and the patient observed for muscle contractions, which should not occur below a voltage at least 3 times the threshold for sensory stimulation.
- ◆ Once the needle position is optimized, a small volume (approximately 1 mL) of nonionic contrast is injected which usually reveals both nerve root spread and epidural uptake.
 - In rare cases where the DRG is located intraspinal or extra-foraminally, one may be seen without the other.^{37,38}
- ◆ Radiofrequency of cervical and thoracic DRG may be performed by either using conventional RF or pulsed radiofrequency.
- ◆ Conventional RF lesions do not typically extend beyond the tip of the electrode. Instead, they extend radially around the active tip in the shape of an oblate spheroid with a maximal effective radius of approximately 2 mm depending on needle diameter.⁴⁰
- The electrode needs to be in close proximity to the targeted neural tissue in order for an effective lesion to be created.
- Previous studies⁴¹⁻⁴⁴ have demonstrated the effectiveness of RF thermoneurolysis for spinal pain of multiple etiologies.
- ◆ *When performing DRG RF procedures, the needle should be placed perpendicular, rather than parallel to the targeted neural tissue.* It is imperative that the clinician be aware of the anatomical position of the DRG and its relationship to other structures.
- ◆ Due to various problems related to conventional RF with neuroma formation and other neurological sequelae, the use of pulsed RF has increased substantially in recent years.
 - During pulsed RF, the targeted neural tissue is subjected to high frequency (300-500 kHz), relatively low voltage (around 40-60 volts) RF pulses, rather than coagulation by continuous, high temperature current.
 - The main advantage of pulsed RF is that unlike continuous thermal RF, it does not result in significant tissue injury.
 - In a study comparing the cellular effects of conventional RF current at 67°C and pulsed RF current at 42°C on DRG morphology in rabbits, Erdine et al⁴⁵ found that animals subjected to both RF modes had increased cytoplasmic vacuolization and enlarged endoplasmic reticulum cisterns compared to sham RF and control groups 2 weeks after lesioning on electron microscopic analysis of their spinal cord and DRG. Yet unlike cells in the continuous RF group, no mitochondrial degeneration or structural pathology in cell or nuclear membranes occurred after pulsed RF current.
 - In a histological study by Podhajsky et al⁴⁶ examining the effects of pulsed and high temperature continuous RF on 118 rat DRG and sciatic nerve specimens, the authors found minor structural changes characterized by fibroblast activation, collagen deposition, and endoneurial edema in both tissue groups. However, these subclinical changes persisted for only 7 days in sciatic nerve specimens compared to 3 weeks in DRG tissue.
 - In the 80°C continuous RF group, tissue specimens showed consistent evidence of Wallerian degeneration. Of note, rats treated with pulsed RF or continuous RF at 42°C exhibited no signs of sensory deficits or paralysis, whereas rats subjected to sciatic nerve continuous RF at 80°C demonstrated immediate foot drop and later developed ulcerative lesions on their feet.
 - In addition to the minor structural changes effectuated by pulsed RF, other possible mechanisms contributing to the analgesic effects include inhibition of excitatory C-fiber responses by repetitive stimulation of A-delta fibers and global reduction of synaptic activity.⁴⁷⁻⁴⁹

Table 4. *Muscle movements associated with DRG stimulation.*

C2	Trapezius
C3	Trapezius
C4	Supraspinatus
C5	Deltoid
C6	Biceps brachii
C7	Triceps
C8	Movement of thumb
T1	Movement of pinky
T2-5	Intercostal muscle contraction may be difficult to observe due to subcutaneous adipose tissue. Should note sensory response radiating to anterior chest wall at appropriate dermatome.
T6-12	Abdominal muscles
L1-3:	Iliopsoas and adductor muscle group of thigh
L4:	Hamstring, quadricept femoris
L5:	Peroneus
S1:	Adductor hallucis
S2:	5th toe movement
S3-5:	Sphincter ani

Side Effects and Complications

Although serious complications are rare with RF procedures, they are not risk-free. There are multiple potential complications associated with transforaminal epidural injections, including intravascular injection, vascular trauma, air and particulate embolism, cerebral thrombosis, epidural hematoma, infection, postdural puncture headaches, neural and/or spinal cord damage and death.⁵⁰⁻⁵⁴ Burns are unusual during RF procedures, but may result from electrical faults, generator malfunction, or insulation breaks in the electrode.^{55,56}

The main concern with DRG procedures are the dozens of reports of paraplegia and death following cervical, thoracic, and even lumbar transforaminal epidural steroid injections. Radicular arteries arising from branches of the aorta (lumbar arteries in the lumbar spine, posterior intercostal arteries in the thoracic spine, and the vertebral and ascending cervical arteries in the cervical spine) constitute a major source of the blood supply to the spinal cord. The upper thoracic and lower cervical cord may be supplied by only one small radiculomedullary artery and is considered a watershed area. In the lower

thoracic region, the large, unpaired artery of Adamkiewicz, which in most people arises between T9 and L2 on the left, almost exclusively supplies the spinal cord, making this area particularly vulnerable to ischemic injury. Whereas most cases of death and permanent neurological injury during cervical and thoracic epidural steroid injections are attributed to inadvertent depot steroid injection into radicular arteries,^{50,54} catastrophic events may also result from vascular injury secondary to needle placement.⁵² Steps that can be taken to reduce the risk associated with DRG procedures include needle positioning toward the posterior aspect of the foramen and advancing the needle in a plane parallel to the nerve root (especially during cervical procedures), the use of digital subtraction and/or real-time imaging during contrast injection, and the avoidance of unnecessary steroid injection.

In a study of 49 patients with chronic postsurgical thoracic pain by Cohen et al,¹⁷ 2 patients developed pneumothoraces, one of whom required hospitalization. Although no long-term complications were reported, Pevzner et al¹⁴ reported a 20% incidence of transient (less than 2 weeks) postprocedure neuritis.

Key Points

1. Radiofrequency DRG procedures have been employed to treat pain Involving the head, neck, arm(s), leg(s), groin and chest.
2. Conditions that have been successfully treated with RF DRG include malignant and nonmalignant pain, and pain of both neuropathic and nociceptive origin.
3. Based on the extant literature, there is strong evidence supporting conventional RF DRG procedures, and weak evidence supporting pulsed RF procedures for chronic pain.
4. Compared to conventional RF DRG, the use of pulsed RF DRG to treat pain appears to carry a much lower incidence of transient neurological complications.
5. The beneficial effects of conventional RF of the DRG tend to abate slowly over time, beginning to decline somewhere around the 6-month mark.
6. Pulsed RF DRG is slightly less efficacious than conventional RF lesioning, with approximately 50% of patients obtaining significant pain relief. Similar to regular RF, the beneficial effects of pulsed RF also diminish with time, lasting between 3 and 5 months on average.
7. In view of the numerous reports of quadriplegia, paraplegia, and deaths following cervical, thoracic and even lumbar transforaminal epidural injections, strict caution is warranted when performing DRG procedures, due to the critical blood supply of the spinal cord.
8. Serious complications are rare with RF procedures of DRG. However, multiple potential complications associated with transforaminal epidural injections may be translated to DRG procedures.

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