Radiofrequency Lesioning of the Cervical Medial Branches

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While radiofrequency (RF) has been used in many clinical contexts, perhaps the most ubiquitous use is in treating cervical facet pain in patients who have suffered whiplash injury. The pathophysiology of these injuries has only recently become clearer.

For many years, whiplash was thought to be caused by a hyperextension injury.[1,2] However, recent studies have shown that normal physiologic ranges of extension are rarely exceeded.[3] Seminal studies by Grauer and coworkers[4] have demonstrated that in a rear-end crash, the seat back pushes the torso forward while the head lags momentarily behind. This novel movement creates an S-shaped curvature of the neck. The kinematics are biphasic, with the largest dynamic elongation of the facet capsular ligaments being observed at the C6-C7 level during this initial S-shaped phase. In the second phase of whiplash all levels of the cervical spine are extended, so that the head reaches its maximum excursion. No injury mechanisms were observed in the second phase.[5] While the initial investigations were in vitro, later experiments in vivo by Kaneoka and colleagues[6] corroborated these findings. Of note, Kaneoka and coworkers also observed facet joint spearing and the stretching of the anterior ligamentous structures.

Facet joint injury is not the only pathology in whiplash and traumatic cervical pain. Recent investigations by multiple researchers have identified central neurologic hypersensitivity in this same population.[7-10] Many of these investigations compare whiplash-injured patients with a normal cohort. These data are consistent with seminal work by Svensson et al[11] on human cadavers exposed to simulated rear-end impacts. This model demonstrates injuries to the dorsal root ganglia in both animal and cadaver subjects.[12,13] These models also demonstrate a "water-hammer" effect seen in the cerebrospinal fluid (CSF) during the types of loading commonly seen in rear-end car crashes.

The concept of facet spearing and ligament injury caused by differential acceleration of the torso and head has led to the design of safety systems based on the neck injury criterion (NIC). The NIC is a mathematical model based initially on injuries to the dorsal root ganglia in rear-end accidents.[11] This model has been validated with cadaver studies showing increasing values of pressure within the CSF with increasing NIC.[13] The results of this research have allowed engineers to deploy such systems as the Volvo WHIPS. These new systems have reduced neck injury claims by as much as 49% when measured against old style seats.[14] These "real world" data go a long way in validating the differential acceleration injury model first proposed by Grauer and colleagues.[4]

While facet joint injury has been implicated in both in vitro and in vivo experimental models, what evidence exists that this injury occurs clinically? Taylor and Twomey[15] have examined cadavers of people who died of major motor vehicle-related trauma compared with control subjects who died of other causes. They have demonstrated hemarthrosis of the cervical facets in subjects who died in auto accidents (Figs 1-3). In addition, the cervical spine does not appear to be alone. Using similar techniques, Taylor and colleagues[16] revealed injuries not visible on standard radiography in a high percentage of lumbar joints. They include fractures of the superior articular process, central infractions of the subchondral bone plate, and tears of the articular capsule, including the ligamentum flavum. The facet joint injuries in young subjects were almost entirely absent from the facet joints of a comparable group of young subjects with no recent history of major trauma. Again, it is clear that more than just facets are likely injured. For instance, Taylor and coworkers[17] have also performed similar experiments and found a significant prevalence of cervical dorsal root ganglion injury, similar to those seen experimentally by Svensson and colleagues.[11] This was as high as 34.5% when only those individuals surviving ($N = 29$) the injury between 2 hours and 7 days were considered.

Clinical anesthesia block studies are another important clue that cervical facet joints and dorsal root ganglia are injured in car crashes. In patients with chronic pain after whiplash who undergo double blinded differential block studies (blocking the medial branch), pain in the distribution of the medial branch of the dorsal ramus can be confirmed in 54% of patients with chronic pain who are referred to a tertiary care center.[18] The most common levels causing pain have been noted to be C2-C3, followed by C5-C6, and then C4-C5. In addition, many whiplash patients report referral patterns that match the cervical facet joint pain patterns mapped out by Dwyer and coworkers.[19] The clinician should take note of these pain referral maps, which have established that facet pain can be referred from the head to the shoulder. These pain maps have shown good agreement with block results.[20]

Treatment-based studies are the final arbiter for the clinician. Cervical RF neurotomy has shown good success in treating chronic postwhiplash pain. This relief appears to be long lasting. The Newcastle group has demonstrated that the effects last 263 days for those treated versus the 8 days for those receiving a placebo.[21] Published in another series of studies, McDonald

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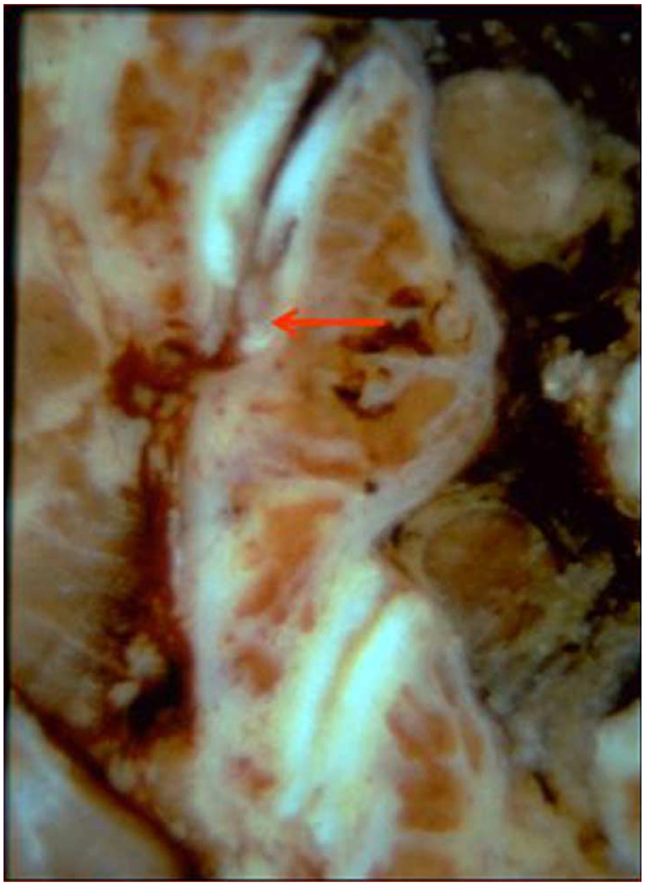

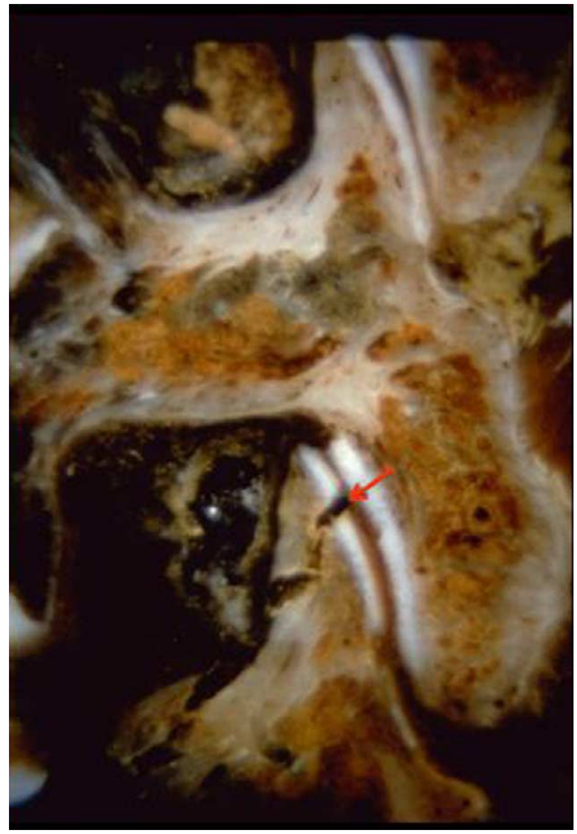

Fig 2. Fractured superior articular process (see arrow).

Figs 1, 2, and 3. Pathological anatomy of the cervical facet joints following motor vehicle accident. Dissections and pictures were kindly provided by Dr James Taylor. Fig 1. Facet joint cartilage disruption (see arrow).

and colleagues[22] found that the mean duration of effect for treatment successes is 422 days. Furthermore, this effect appears to be independent of litigation status.[23]

Finally, this treatment also appears to have an impact on what was previously considered psychosomatic complaints.[24] Wallis and coworkers[24] studied 17 patients with a single painful cervical facet joint who reported psychological distress. All showed elevated scores for psychosomatic behavior on a Symptom Checklist-90. The patients were then treated with RF neurotomy in a placebo controlled, double blinded fashion. All patients who experienced complete pain relief exhibited resolution of their preprocedure psychological distress. In contrast, all but 1 of the patients whose pain remained unrelieved continued to demonstrate psychological distress.

Anatomical Considerations

Cervical RF lesioning is largely focused on the posterior column innervation, which is represented by the medial branches of the cervical dorsal rami. Recent cadaver dissections have shown that every medial branch from the dorsal rami of the C3-C8 spinal nerves passes through an anatomic tunnel dorsolateral to the facet joint.[25] The nerve then passes laterally around the articular pillar (Fig 4). The course of the nerve has been mapped by placing copper wires over the dissected nerve and superimposing several specimens onto radiographic film.[26]

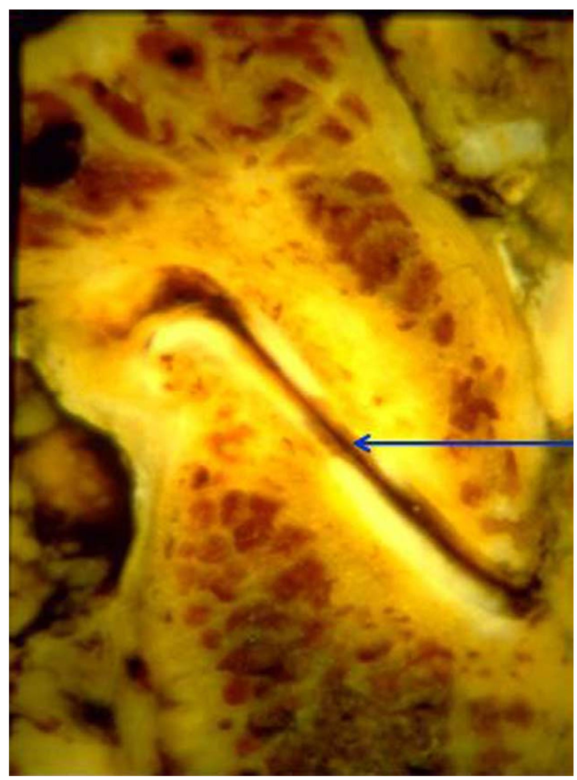

Fig 3. Facet joint hemarthrosis (see arrow).

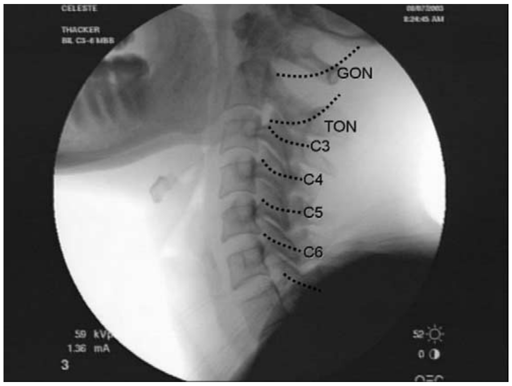

Fig 4. A stylized diagram of the greater occipital nerve (GON), third occipital nerve (TON), and C3-C6 medial branches superimposed on a lateral radiograph. Connections between the GON and TON are not shown.

As a rule, for C3-C6 medial branches, the nerve always passed through the centroid of the bisecting lines created by trapezoidal shape of the articular pillar (see Fig 5). Since the nerve innervates the facet joint from above and below, it is necessary to block the medial branch of the named nerves at that spinal level. For instance, the C3-C4 facet joint is innervated by the medial branches of the C3 and C4 dorsal rami. While this holds true for the C3-C6 medial branches, there are differences in both the upper and the lower cervical spine. The C2-C3 joint is supplied by a large third occipital nerve (which later becomes cutaneous just below the nuchal line) as well as afferents from C2, the position of which may be variable.[27] The lower cervical medial branches also have a nerve course that differs from the midcervical spine. The target for the C7 medial branch lies on the superior-medial tip of the C7 transverse process, while the target for the C8 medial branch lies on the superior lateral aspect of the T1 transverse process.[28] Therefore, to block the C7-T1 joint, the C7 and C8 medial branches must be injected.

It should also be noted that the medial branch innervates far more than the cervical facet joint. Recent anatomical investigations have shown that the nerve receives sprouts from the bony lamina and spinous process as well innervating the surrounding musculature.[29] This includes the deep segmental stabilizers of the spine (multifidus) as well the semispinalis capitus and semispinalis cervicis.

Block Technique and Paradigm

Barnsley and Bogduk[30] have investigated the radiographic contrast spread during cervical medical branch blocks to determine if the target structure is contacted by injectate while sparing

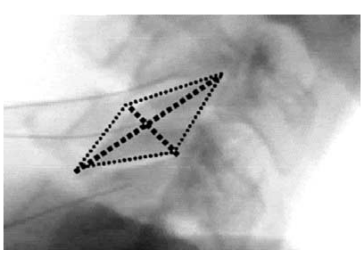

Fig 5. The bisection of the centroid is the needle target. Note that the needle tip shown is located at this bisection.

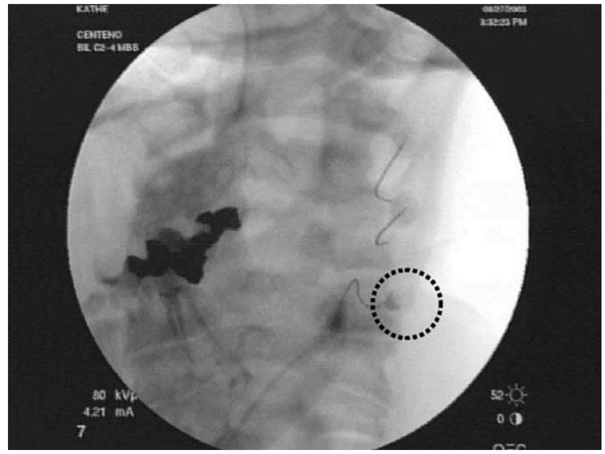

Fig 6. AP position for a right C2, C3, C4 medial branch block. Note that the patient's head is turned to the left. Also note the contrast spreading in the articular groove of C4 (dotted circle). The C2 needle is placed at the middle of the C2-C3 joint.

unwanted structures that could confound results. This investigation did reveal specificity of this technique for the medial branch.

It should be noted that a significant false positive rate has been found for single-event cervical medial branch blocks, as determined by Barnsley and coworkers[31] to be 27% (95% confidence interval, 15%-38%). As a result, double blocks are recommended for confirmation before proceeding to RF lesioning.

The posterior and lateral fluoroscopically guided approaches to access the cervical medial branch seem to be the most widely used. For the more common posterior approach, the patient is placed prone on a radiographic table, with the cervical spine in a flexed position and the head turned opposite the target side. The C-arm is adjusted to an AP view with caudal tilt to allow the waist of the target articular pillar to appear perpendicular to the x-ray beam. The needle is inserted for an initial target at the posterior waist of the articular pillar. Once bone is contacted, the needle is walked off into the lateral portion of the groove in the articular pillar. A lateral x-ray view is then checked with adjustment of the needle. For the C3-C6 medial branches, the target is the centroid of the lines that bisect the trapezoid of the articular pillar (see Figs 5, 6, and 7). To block the C2-C3 joint, afferents from C2 (posterior primary ramus supplying the superior portion of the C2-C3 joint), the third occipital nerve, and the C3 medial branch must be covered. In addition, this block is further confounded by the fact that the C3 communicating loop crosses the dorsal aspect of C2-C3 and may send articular branches to the joint. To avoid these pitfalls, the needle position should be both above and below the joint line laterally as well as just dorsal to the joint. For the C7 medial branch, the target is the superior-medial aspect of the C7 transverse process and "walked off" the leading edge (approximately 2 mm anterior). For the C8 medial branch, a similar approach may be taken at the superior-medial aspect of the T1 transverse process. This target only allows access to the articular branch of the nerve. If the entire distribution of the C8 medial branch is the target, the block should be performed on the superior lateral tip of the T1 transverse process (see Fig 8). This is because the main trunk of the C8 medial branch is located superior lateral on the T1 transverse process.[32]

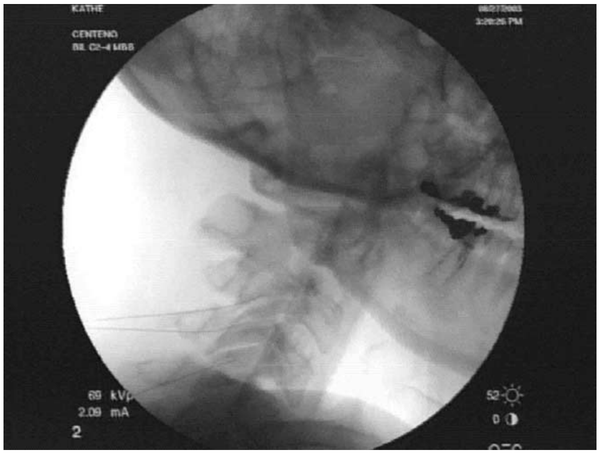

Fig 7. Lateral position for a third occipital, C3, and C4 medial branch block. Note that the third occipital needle is located at the midportion of the C2-C3 facet joint, while the C3 and C4 needles are located at the midportion of the centroid formed by the lateral articular pillar.

Pain measurement and assessment is a key part of any diagnostic block paradigm. Both preprocedure and postprocedure visual analog scale (VAS) scores should be obtained. In addition, care should be taken to ascertain which symptoms have been helped by the block. For example, a patient who has both head and neck pain may report their post-VAS pain score as a 5/10, but when questioned further will admit that their headache is gone but their neck pain remains a 5/10.

Radiofrequency Lesioning—Theoretical Aspects

The technique of RF lesioning for the nervous system started with Rosomoff and coworkers,[33] in 1965, as a more precise method of percutaneous cordotomy. By the early 1980s, Sluijter and Koetsveld-Baart [34] described techniques for percutaneous coagulation of the cervical dorsal rami. In this technique, electrodes were placed lateral to the cervical facet joints. The goal of this approach was mainly to reduce pain of radicular origin.[35] This technique appeared to be effective with very little deafferentation pain and no motor denervation in the 20 patients studied.[36] The use of this technique to perform a "rhizotomy" of the cervical facet joints was first reported by Schaerer.[37] In this technique, electrodes were placed onto the transverse processes. While the dorsal ramus was denervated from this point, Bogduk[38] raised concerns that there were risks that the electrode may be placed too far laterally away from the medial branch. Additional concerns that the electrode tip needed a bony landmark to define depth led to the suggestion of the current recommendations for positioning.

The current application of cervical RF lesioning has led to 2 major camps: continuous and pulsed RF. The early pioneers of continuous RF used a tip temperature of 75°C delivered through a large electrode diameter, which provided lesions of significant size.[39] This may have attributed to the lack of early interest in this technique. The development of small-diameter electrodes for the treatment of spinal pain assisted the spread of the technique and allowed access to the anterior column without damaging the exiting nerve roots. All modern RF techniques use these smaller needle diameters.

Radiofreqiency treatment is applied through an insulated electrode where the active tip is left uninsulated. This distal active tip varies in length between 2 mm and 15 mm. The patient is insulated by a grounding pad, where the current entering the body through the electrode must be equal to the current leaving the body through the ground. There are 2 important events occurring at the electrode tip: the formation of heat and the exposure of tissue to an electrical field.[40]

To examine the properties of both continuous and pulsed RF, the basic principles of lesion generation must be fully understood. Heat is formed by tissue resistance to RF current flow. The formation of heat will be the greatest where the current density is largest, which is around the electrode tip. A continuous RF lesion causes tissue coagulation in a slightly pear-shaped area with the base of this shape at the proximal end of the active tip and the smaller apex at the distal electrode tip. At the same time heat is being formed by tissue resistance to current flow, heat is also being washed out by dissipation into the surrounding tissue and the circulation. The second property of lesion generation is the shape of the electrical field, which is unaffected by the resulting formation of heat. This pattern is more akin to a magnetic field distribution. The intensity of the forward electrical field depends on the shape of the electrode tip. The clinical significance of this phenomenon is that strong electrical fields are generated by sharp-tipped electrodes while weak fields are generated by blunt- or flat-tipped electrodes.[41] To summarize these 2 effects, the production of heat spreads sideways and parallel to the shaft with little spread forward to the electrode tip. The electrical field projects strongly forward from sharp tips and is weak along the shaft of the electrode tip. These properties mean that to provide a target with maximum exposure to heat, the electrode should be positioned parallel to the nerve; for maximum expose to an electrical field, the electrode should be perpendicular to the nerve (see Fig 9).

The early focus of RF lesioning was neuroablation. However, complete ablation of a sensory nerve had some undesirous side effects including deafferentation pain and hypoesthesia. As a result, the focus soon shifted to a selective C-fiber lesion, which would modulate pain but leave the larger sensory fibers intact. Heat was thought to be a good solution to selective neuroabla-

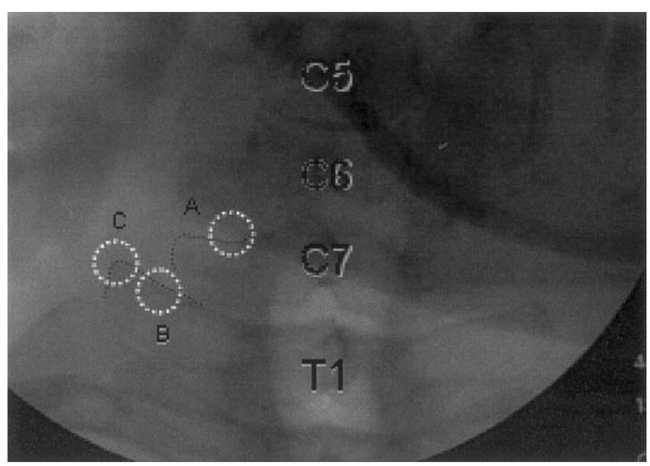

Fig 8. C7 and C8 medial branch block and RF targets. The C7 target is the superior-medial portion of the transverse process (A). Two C8 medial branch targets are shown (B and C). The B target (superior-medial) blocks only the articular branch. The C target (superior-lateral) blocks the entire medial branch distribution.

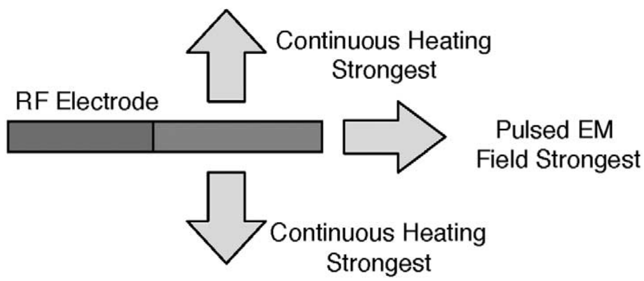

Fig 9. Pulsed versus continuous RF properties at the active electrode tip.

tion of C-fibers based on an animal model.[42] However, replicating these findings have proven difficult.[43,44] In 1 animal model where the dorsal root ganglion lesion conditions were much more thoroughly controlled, there was only temporary loss of all myelinated fibers. Based on these data and the observations of many practitioners that lower temperature RF lesions produce acceptable clinical outcomes. It is unknown if heat is the property of RF that causes the clinical effect.

At this time, the cervical RF community is presented with a clinical dilemma. The vast majority of blinded, randomized controlled cervical studies have used a continuous and "hot" lesion. For example, the medial branch lesions created in the long-term follow-up study by McDonald were 80°C for 90 seconds. However, to reduce postprocedure skin hypersensitivity, many practitioners have switched to a pulsed 42°C lesion.

What data exist that a warm, pulsed 42°C lesion is effective? Early animal studies with this technique appear to demonstrate that pulsed RF (but not continuous RF at the same temperature) activates pain-processing neurons in the dorsal horn.[45] Early clinical case series suggest that the pulsed technique is effective in neuropathic pain states such as end-stage trigeminal neuralgia.[46,47] While more long-term randomized controlled trials are needed for the pulsed RF, the choice of a hot or cold lesion is left up to the individual practitioner.

Technical Aspects of RF Lesion Generation

As alluded to earlier, positioning of the electrode is key, based on the property of RF that is being optimized. Heat lesions are optimized by placing the electrode parallel to the medial branch. This means that on a posterior approach, the needle is placed parallel to the groove in the articular pillar. To optimize the electrical properties of RF, the electrode tip is placed perpendicular to the medial branch. A lateral approach is better suited for this pulsed technique.

One of the advantages of RF is that the electrode can deliver a lower intensity stimulus to assist in identifying the exact location of the medial branch and to reproduce concordant pain. Patient-blinded stimulus (0.2-0.3 V at 50 Hz) that reproduces concordant pain in conjunction with segmental contraction of the multifidus confirms that the electrode is placed in the correct location to begin lesion generation. If multifidus contraction is seen without symptom generation, this site should not be lesioned.

A hot lesion is defined as a temperature of 80°C to 90°C for 60 to 90 seconds. A cold or warm lesion is defined as 38°C to 42°C at 500 Hz for 60 to 90 seconds. Temperatures of 60°C to 70°C have also been used to treat the dorsal root ganglion.

The continuous cervical medial branch lesioning technique is identical to the medial branch block techniques already described. The tip of the electrode is placed parallel to the medial branch as it runs in the waist of the lateral articular pillar (see Fig 10). On a lateral view, this appears as if the tip of the electrode is laid across the waist or midportion of the articular pillar (see Fig 11). Once the nerve has been located, a small amount of lidocaine is instilled through the cannula. Since the active uninsulated electrode tip must make contact with the medial branch, a 4-mm tip length is commonly used for C3-C6. Care should be taken so that the tip is not advanced into the intervertebral foramen.

Fig 10. RF electrodes placed in the groove of the articular pillar on an AP view.

Some practitioners have advocated a 2-lesion approach, with both posterior and oblique approaches for each medial branch to be lesioned.[48] This technique is used to avoid missing aberrant nerve courses. In addition, the maximum effective radius of an RF lesion is not reliable at more than 1 electrode diameter.[49] This means that to create a wider continuous lesion, the electrode tip must be placed, at maximum, 1 diameter from the last lesion. While the 2-lesion approach appears to be very comprehensive, a single posterior approach appears to be more common.

For lesioning of the C2-C3 level (see Fig 12), the target points lie on a vertical line that bisects the lateral portion of the C2-C3 joint. The upper target area lies opposite the level of

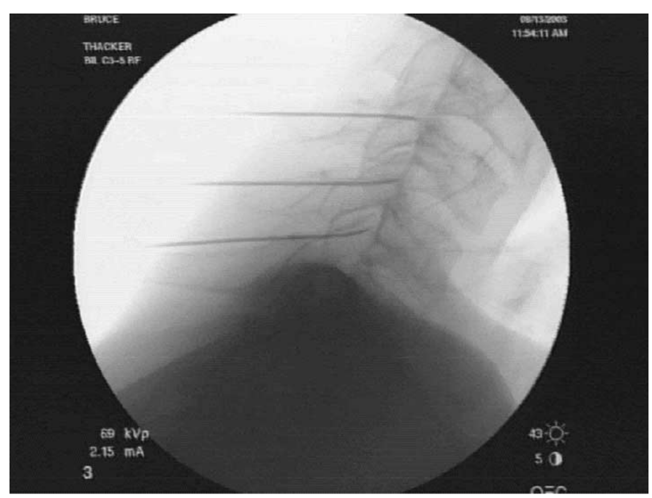

Fig 11. Lateral placement of cervical RF electrodes. Note that the tip of the electrode runs across the middle of the articular pillars.

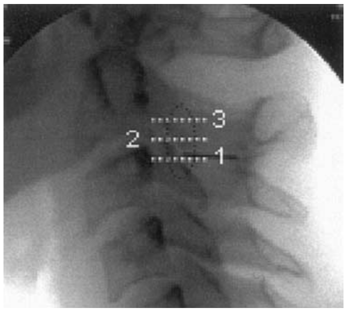

Fig 12. RF lesioning points for the C2-C3 joint. The dotted oval represents the approximate target area. Line 1 is opposite the bottom of the C2-C3 foramen, line 2 is opposite the midpoint of the lateral C2-C3 joint line, and line 3 is opposite the C3 superior articular process.

the apex of the C3 superior articular processes (just above the joint line). The lower target area lies opposite the bottom of the C2-C3 intervertebral foramen (just below the joint line). The middle point lies midway between the upper and lower points, usually on the subchondral plate of the superior articular process of C3 (at the joint line).

For lesioning of the lower cervical medial branches, either a 50- or 100-mm cannula with a 5-mm active tip can be used. As in the block technique, the cannula is directed 2 mm over the leading edge of the transverse process. Stimulation is then performed, paying close attention to any unwanted fasciculations in the upper extremity.

Contraindications

The following is a list of contraindications listed by the International Spinal Injection Society:

Absolute

- Bacterial infection—systemic or localized in the region of the blocks to be performed.
- Possible pregnancy.
- Bleeding diathesis—due to hematological disease or anticoagulants.

Relative

- (Blocks only) Allergy to contrast media—may require coverage with corticosteroid and H1 and H2 antagonists.
- (Blocks only) Allergy to local anesthetics—may require identification of a class of anesthetic to which the patient is not allergic.
- Compromise of coagulation—on treatment with nonsteroidal anti-inflammatory medications, including aspirin.

Complications

Major complications from cervical RF lesioning are rare. Ataxia has been reported as a result of third occipital neurotomy.[50] In addition, concerns have been raised that denervating a cervical facet joint may lead to a Charcot joint.[51] McDonald and coworkers[48] have argued against this claim. At this time, no long-term studies regarding this issue have been conducted. In addition, continuous RF lesions can produce transient cutaneous hypersensitivity. Anecdotal reports are that this problem is less significant with pulsed RF, although there is currently a lack of literature on the subject.

Medical-Legal Considerations

Since many of the patients who receive cervical RF have been injured in a motor vehicle collision, medical-legal concerns will undoubtedly arise for the cervical RF practitioner. As it was noted above, the Sapir study[23] found no statistical difference in the amount of pain relief obtained from this procedure between litigants and nonlitigants. In addition, the Newcastle group[21] has found that the psychological distress so common in late whiplash patients (as measured on a Symptom Checklist-90) resolved after cervical RF treatment. Perhaps the biggest medical-legal concern for the RF practitioner is an estimate of future costs for the procedure. Since no long-term studies lasting 10 years or longer have yet been published, it is unknown exactly how long any 1 patient is likely to need RF performed. However, as long as the procedure continues to provide long-term relief and no complications arise, it is assumed that patients will require the treatment on an ongoing basis.

References

1. Shea M, Wittenberg RH, Edwards WT, et al: In vitro hyperextension injuries in the human cadaveric cervical spine. J Orthop Res 10:911-916, 1992
2. Janecki Jr CJ, Lipke JM: Whiplash syndrome. Am Fam Physician 17:144-151, 1978
3. Siegmund G, Brault J, Wheeler JB: The relationship between clinical and kinematic responses from human subject testing in rear-end automobile collisions. Accid Anal Prev 32:207-217, 2000
4. Grauer JN, Panjabi MM, Cholewicki J, et al: Whiplash produces an S-shaped curvature of the neck with hyperextension at lower levels. Spine 22:2489-2494, 1997
5. Panjabi MM, Cholewicki J, Nibu K, et al: Biomechanics of whiplash injury. Orthopade 27:813-819, 1998
6. Kaneoka K, Ono K, Inami S, et al: Motion analysis of cervical vertebrae during whiplash loading. Spine 24:763-76915; discussion 770, 1999, 1999
7. Moog M, Quintner J, Hall T, et al: The late whiplash syndrome: A psychophysical study. Eur J Pain 6:283-294, 2002
8. Sterling M, Treleaven J, Jull G: Responses to a clinical test of mechanical provocation of nerve tissue in whiplash associated disorder. Man Ther 7:89-94, 2002
9. Curatolo M, Petersen-Felix S, Arendt-Nielsen L, et al: Central hypersensitivity in chronic pain after whiplash injury. Clin J Pain 17:306-315, 2001
10. Sterner Y, Toolanen G, Knibestol M, et al: Prospective study of trigeminal sensibility after whiplash trauma. J Spinal Disord 14:479-486, 2001
11. Svensson MY, Aldman B, Bostrom O, et al: Nerve cell damages in whiplash injuries. Animal experimental studies. Orthopade 27:820-826, 1998
12. Ortengren T, Hansson HA, Lovsund P, et al: Membrane leakage in spinal ganglion nerve cells induced by experimental whiplash extension motion: A study in pigs. J Neurotrauma 13:171-180, 1996
13. Eichberger A, Darok M, Steffan H, et al: Pressure measurements in the spinal canal of post-mortem human subjects during rear-end impact and correlation of results to the neck injury criterion. Accid Anal Prev 32:251-260, 2000
14. Insurance Institute for Highway Safety, Highway Loss Data Institute, October 22, 2002
15. Taylor JR, Twomey LT: Acute injuries to cervical joints: An autopsy study of neck sprain. Spine 9:1115-1122, 1993
16. Taylor JR, Twomey LT, Corker M: Bone and soft tissue injuries in post-mortem lumbar spines. Paraplegia 28:119-129, 1990
17. Taylor JR, Twomey LT, Kakulas BA: Dorsal root ganglion injuries in 109 blunt trauma fatalities. Injury 29:335-339, 1998

18. Barnsley L, Lord SM, Wallis BJ, Bogduk N: The prevalence of chronic cervical zygapophysial joint pain after whiplash. Spine 20:20-25discussion 26, 1995
19. Dwyer A, Aprill C, Bogduk N: Cervical zygapophyseal joint pain patterns. I: A study in normal volunteers. Spine 15:453-457, 1990
20. Aprill C, Dwyer A, Bogduk N: Cervical zygapophyseal joint pain patterns. II: A clinical evaluation. Spine 15:458-461, 1990
21. Lord SM, Barnsley L, Wallis BJ, et al: Percutaneous radio-frequency neurotomy for chronic cervical zygapophyseal-joint pain. N Engl J Med 335:1721-1726, 1996
22. McDonald GJ, Lord SM, Bogduk N: Long-term follow-up of patients treated with cervical radiofrequency neurotomy for chronic neck pain. Neurosurgery 45:61-67discussion 67-68, 1999
23. Sapir DA, Gorup JM: Radiofrequency medial branch neurotomy in litigant and nonlitigant patients with cervical whiplash: A prospective study. Spine 26:E268-E273, 2001
24. Wallis BJ, Lord SM, Bogduk N: Resolution of psychological distress of whiplash patients following treatment by radiofrequency neurotomy: A randomised, double-blind, placebo-controlled trial. Pain 73: 15-22, 1997
25. Zhang J, Tsuzuki N, Hirabayashi S, et al: Surgical anatomy of the nerves and muscles in the posterior cervical spine: A guide for avoiding inadvertent nerve injuries during the posterior approach. Spine 28:1379-1384, 2003
26. Bogduk N: The clinical anatomy of the cervical dorsal rami. Spine 7:319-330, 1982
27. Lord SM, Barnsley L, Wallis BJ: Third occipital nerve headache: A prevalence study. J Neurol Neurosurg Psychiatry 57:1187-1190, 1994
28. Bogduk N: The clinical anatomy of the cervical dorsal rami. Spine 7:319-330, 1982
29. Zhang J, Tsuzuki N, Hirabayashi S, et al: Surgical anatomy of the nerves and muscles in the posterior cervical spine: A guide for avoiding inadvertent nerve injuries during the posterior approach. Spine 28:1379-1384, 2003
30. Barnsley L, Bogduk N: Medial branch blocks are specific for the diagnosis of cervical zygapophysealjoint pain. Reg Anesth 18:343-350, 1993
31. Barnsley L, Lord S, Wallis B, et al: False-positive rates of cervical zygapophysial joint blocks. Clin J Pain 9:124-130, 1993
32. Chua WH, Bogduk N: The surgical anatomy of thoracic facet denervation. Acta Neurochir (Wien) 136:140-144, 1995
33. Rosomoff HL, Brown CJ, Sheptak P: Percutaneous radiofrequency cervical cordotomy: Technique. J Neurosurg 23:639-644, 1965
34. Sluijter ME, Koetsveld-Baart CC: Interruption of pain pathways in the treatment of the cervical syndrome. Anaesthesia 35:302-307, 1980
35. Sluijter ME: Percutaneous facet denervation and partial posterior rhizotomy. Acta Anaesthesiol Belg 32:63-79, 1981
36. van Kleef M, Spaans F, Dingemans W, et al: Effects and side effects of a percutaneous thermal lesion of the dorsal root ganglion in patients with cervical pain syndrome. Pain 52:49-53, 1993
37. Schaerer JP: Radiofrequency facet rhizotomy in the treatment of chronic neck and low backpain. Int Surg 63:53-59, 1978
38. Bogduk N: The clinical anatomy of the cervical dorsal rami. Spine 7:319-330, 1982
39. Schmidel E, Sweet W: Percutaneous electrocoagulation of spinal nerve trunk, ganglion and rootlets. Current Technique in Operative Neurosurgery. New York, NY, Grune and Stratton, 1977
40. Cosman ER, Nashold BS, Ovelman-Levitt J: Theoretical aspects of radiofrequency lesions in the dorsal root entry zone. Neurosurgery 15:945-950, 1984
41. Sluijter M: Radiofrequency Part I. FlivoPress SA, Meggan (LU), Switzerland, 2001
42. Letcher FS, Goldring S: The effect of radiofrequency current and heat on peripheral nerve actionpotential in the cat. J Neurosurg 29:42-47, 1968
43. Smith HP, McWhorter JM, Challa VR: Radiofrequency neurolysis in a clinical model. Neuropathological correlation. J Neurosurg 55:246-253, 1981
44. de Louw AJ, Vles HS, Freling G, et al: The morphological effects of a radio frequency lesion adjacent to the dorsal root ganglion (RF-DRG)—An experimental study in the goat. Eur J Pain 5:169-174, 2001
45. Higuchi Y, Nashold BS Jr, Sluijter M, et al: Exposure of the dorsal root ganglion in rats to pulsed radiofrequency currents activates dorsal horn lamina I and II neurons. Neurosurgery 50:850-855discussion 856, 2002
46. Van Zundert J, Brabant S, Van de Kelft E, et al: Pulsed radiofrequency treatment of the Gasserian ganglion in patients with idiopathic trigeminal neuralgia. Pain 104:449-452, 2003
47. Munglani R: The longer term effect of pulsed radiofrequency for neuropathic pain. Pain 80:437-439, 1999
48. McDonald GJ, Lord SM, Bogduk N: Long-term follow-up of patients treated with cervical radiofrequency neurotomy for chronic neck pain. Neurosurgery 45:61-67, 1999
49. Bogduk N, Mcintosh J, Marsland A: Technical limitations to the efficacy of radiofrequency neurotomy for spinal pain. Neurosurgery 20:529-535, 1987
50. Lord SM, Barnsley L, Bogduk N: Percutaneous radiofrequency neurotomy in the treatment of cervical zygapophysial joint pain: A caution. Neurosurgery 36:732-739, 1995
51. Drinka PJ, Jaschob K: Treatment of chronic cervical zygapophyseal-joint pain. N Engl J Med 336:1530-1531, 1997