

Neurostimulation for Pain of Spinal Origin

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INTRODUCTION

Neurosurgical procedures for pain may be anatomic (attempting to correct the physical cause of the pain), ablative (destroying pain pathways), or augmentative (modulating the existing neurological anatomy and physiology). The available augmentative procedures, commonly referred to under the umbrella “neuromodulation,” include spinal cord stimulation (SCS).

Although augmentative procedures are reversible and can be tested through screening trials before a device is implanted for chronic use, they have, until recently, been reserved for patients who failed to gain relief through anatomic or ablative procedures and had exhausted the possibilities offered by other alternative therapies. The high initial cost of augmentative therapy might explain this bias.

SCS is an augmentative procedure that relies on artificially generated paresthesia to achieve pain relief by replacing the sensation of pain with one that is commonly described as “tingling.” To be effective, the paresthesia must cover the topography of the pain. The major determinant of the distribution of paresthesia is the spinal location of the stimulating cathodes and anodes.² Programmable pulse generators allow noninvasive, post-implantation selection of various electrode contact combinations.

The major indication for SCS in the United States is failed back surgery syndrome (FBSS). This catch-all diagnosis is made when one or more previous operations on the spine fails to provide a patient with long-term pain relief. In part, because FBSS patients are not distinguished on the basis of the various indications for the initial operation or according to the suspected reason for the failures, FBSS is particularly difficult to treat.

SPINAL CORD STIMULATION VERSUS REOPERATION FOR FBSS

In 1991, our research group published a paper detailing our 5-year follow-up data for FBSS patients treated with repeat operation⁵ and a companion paper presenting 5-year results for FBSS patients treated with spinal cord stimulation (SCS).⁶

For the reoperation group, analysis of follow-up data collected at a mean of 5.05 years postoperatively by a disinterested third party from 102 patients who had undergone an average of 2.4 previous operations, revealed that only 34% reported a successful outcome. Postoperatively, 21 disabled patients returned to work, but 15 stopped work. The number of patients who reported a loss in neurological function exceeded those who reported a gain. Most patients, however, reduced or eliminated their use of pain medication.⁵

Analysis of factors that prognosticated a favorable result for reoperation among these patients revealed an advantage in being female, young, and employed, as well as in having no suspected epidural fibrosis and predominately radicular pain. Because most FBSS patients are unlikely to have these characteristics, however, and the retrospective study revealed such a low long-term success rate, we concluded that an alternative to yet another reoperation should be considered for FBSS patients.⁵

At the time we published these reports, SCS was reserved for FBSS patients who were no longer candidates for repeat operation (they did not have a surgically remediable lesion). Thus, our smaller series of 50 SCS patients averaged 3.1 previous operations. Analysis of data collected by a disinterested third party revealed that 53% of the patients reported success from SCS at mean follow-up period of 2.2 years, and 47% maintained this success at 5 years. Despite the drop-off in the success rate, which was not unusual in an SCS series reported at that time, and despite the increased number of failed previous operations compared with the patients whom we treated with reoperation, SCS was, thus, a more successful therapy than reoperation for FBSS.⁶

Most of the SCS patients reported improvement in their ability to participate in most activities of daily living and few lost neurological function. Most also reduced or eliminated consumption of pain medication and 25% of those who had been disabled returned to work. As with reoperation, being female was an advantage, as was having a multi-contact SCS system that could be reprogrammed to ensure pain/paresthesia coverage.⁶

The results of these retrospective analyses led us to design a study that would provide a direct, prospective, randomized comparison of SCS versus reoperation for FBSS (see *Fig. 30.1* for the study design).¹⁰ To mimic real-life

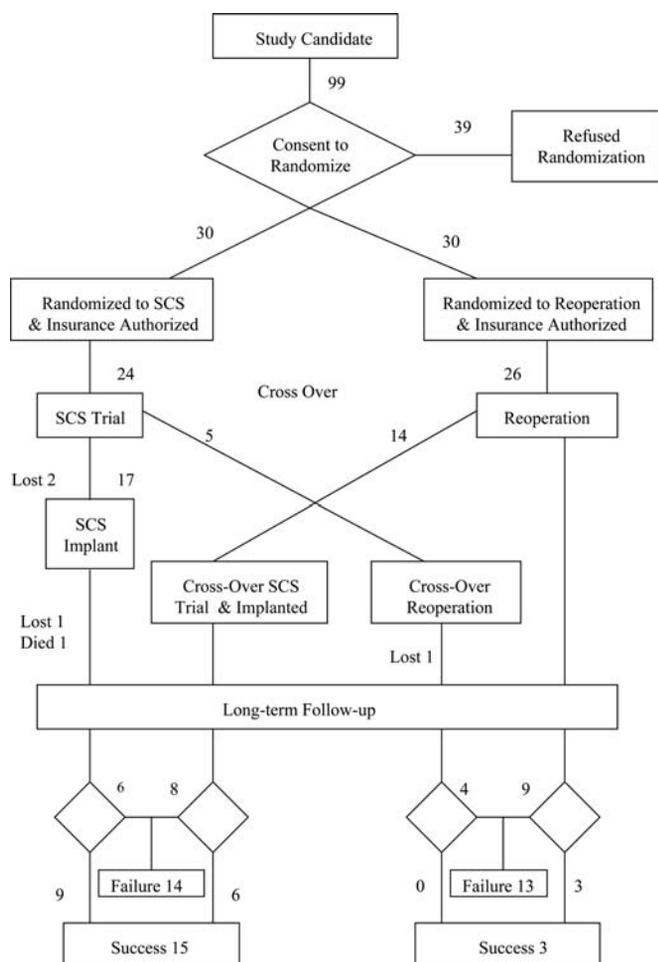


FIGURE 30.1 Study design and results for cross-over randomized trial comparing the outcome of reoperation and spinal cord stimulation in failed back surgery syndrome patients (from, North RB, Kidd DH, Farrokhi F, Piantadosi S: Spinal cord stimulation versus repeated lumbosacral spine surgery for chronic pain: A randomized, controlled trial. *Neurosurgery* 56:98–106, 2005).

therapeutic decisions, we decided to include an option for patients randomized to one arm to cross to the other arm at a reasonable interval after the initial therapy (immediately after SCS failed or 6 months postoperatively in the group randomized to reoperation).

In addition to our usual definition of success (more than 50% pain relief and patient satisfaction), we considered the cross-over decision a primary study endpoint; that is, a patient could not be counted as a success of one treatment if he or she crossed over to the other. We also included medication requirement, work status, and ability to engage in activities of daily living as outcome measures.¹⁰

All patients in this study had FBSS with lumbosacral radicular pain equal to or greater than the harder-to-treat axial

low back pain. In addition, all had surgically remediable root compression with or without an indication for fusion or instrumentation (confirmed by a second opinion). Types of operations proposed and performed were uniformly distributed across the study groups.¹⁰

The study exclusion criteria were existence of a disabling neurological deficit (foot drop, bladder problem) attributable to the remediable root compression, a complete myelographic block, a significant untreated inappropriate drug dependency, a major psychiatric comorbidity, a coexisting chronic pain problem in another location, and a prominence of functional, non-organic signs.¹⁷

Data were collected from the patients' hospital and surgical records and from patient interviews conducted by disinterested third parties. To test for external validity, we followed the entire population eligible for the study, including those who refused randomization (who were significantly younger than those who entered the study) and the patients receiving Worker's Compensation who accepted randomization, but could not obtain third-party authorization. This obstacle made Worker's Compensation patients significantly less likely than other patients to be enrolled in the study. All patient subgroups were successfully followed long-term.¹⁰

Our first significant finding was that only five of the 24 patients randomized to SCS crossed to reoperation versus 14 of the 26 patients randomized to reoperation. At an average of 3 years follow-up in 45 (90%) of the 50 randomized patients, we found that SCS was significantly more successful than reoperation, with nine out of 19 available SCS patients reporting success versus only three out of 26 available reoperation patients. None of the five patients randomized to SCS who crossed to reoperation reported success, but six of the 14 patients randomized to reoperation found success with SCS as their last intervention (Fig. 30.1). Thus, 47% of patients randomized to SCS were successes compared with 43% of those who received SCS after yet another reoperation. In a worst case analysis (assuming that all of the patients lost to follow-up were failures), the superior outcome of SCS versus reoperation remained significant.¹⁰

Significantly more patients randomized to reoperation increased their consumption of opioids (n = 11) compared with patients randomized to SCS (n = 3). No significant difference occurred in ability to perform activities of daily living or in work status.¹⁰

Because the initial high cost of SCS can be a barrier to its use, we analyzed the health care cost data for a subgroup of 21 patients randomized to reoperation and 19 randomized to SCS.⁹ The long-term follow-up (per patient) cost of success was \$48,357 for patients treated only with SCS, \$105,691 for those treated only with reoperation, and \$115,986 for reoperation patients who crossed over to SCS. The patients randomized to SCS who crossed over to reop-

eration accumulated the highest per patient (\$260,611) cost despite the lack of successful outcome.⁹

As a result of these studies, we concluded that, for patients with FBSS whose conditions do not demand an immediate operation, 1) SCS is a significantly more effective treatment than reoperation and, in most cases, obviates the need for reoperation; 2) SCS is more cost-effective than reoperation; and 3) SCS should be the initial therapy of choice in these patients for these reasons and because the outcome of SCS is best among FBSS patients with the fewest previous failed operations.

THE TECHNICAL AND CLINICAL IMPACT OF ELECTRODE DESIGN

To improve the outcome of SCS, we must continue to improve not only hardware design and patient selection, but also our understanding of the best choice of stimulating system to implant in which patients and the best way to adjust stimulation parameters to optimize clinically useful pain/paresthesia overlap.

Computerized Analysis of Technical Results

To conduct the necessary studies to optimize stimulator adjustment, we developed an interactive computerized method in our laboratory in 1984.^{8,15} Using this system, patients enter a pain drawing and then draw the area of paresthesia achieved with various stimulation parameter settings and various electrode contact assignments. For each test, the patients rate their pain/paresthesia overlap on a visual analogue scale, and the computer quantifies this by counting pixels. These two quantitative methods are highly correlated. Using the computer, the patient can quickly test a multitude of contact combinations and parameter settings (*Fig. 30.2*).

RCT Comparing the Technical and Clinical Impact of Two Basic Electrode Designs

We used our computerized system to conduct a prospective, randomized, controlled trial comparing the technical¹¹ and clinical¹⁴ outcome of SCS with a four-contact percutaneous electrode versus a four-contact, insulated laminectomy electrode (see *Table 30.1* for the electrode specifications and (*Fig. 30.3*) for the position of a percutaneous and insulated electrode in the spinal canal).

Technical Results

We randomized 24 FBSS patients who passed the SCS screening trial and underwent computerized testing with the temporary percutaneous electrode into two equal groups. Upon implantation of the SCS system, Group P received a new percutaneous four-contact electrode that was identical to the test electrode and Group L received an insulated four-contact laminectomy electrode. For all patients, the results of the screening trial provided control data. All implanted elec-

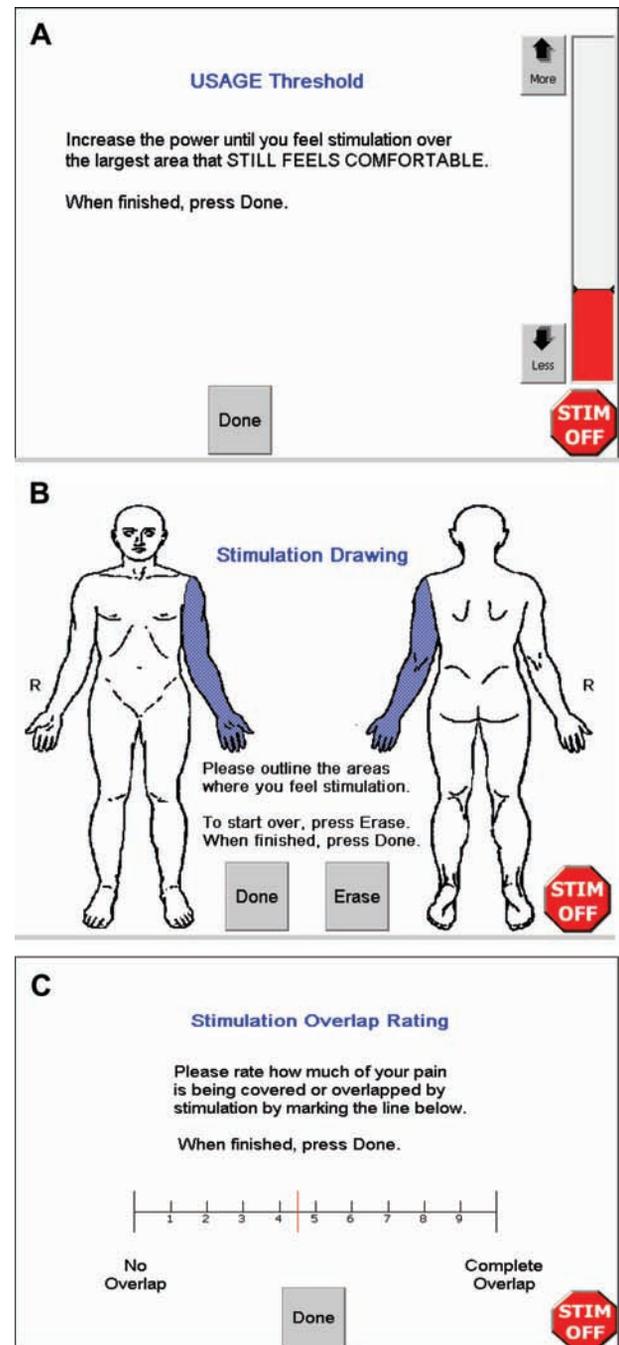


FIGURE 30.2 Our computerized stimulation adjustment system is patient-interactive. *A*, the patient draws the area of pain and adjusts the stimulation amplitude. *B*, next, the patient draws the area of paresthesia. *C*, finally, the patient rates pain/paresthesia overlap. The patient then waits for the paresthesia to subside before testing another set of parameters (*from*, North RB, Brigham DD, Khalessi A, Calkins S, Piantadosi S, Campbell DS, Daly MJ, Dey B, Barolat G, Taylor R: Spinal cord stimulator adjustment to maximize implanted battery longevity: A randomized, controlled trial using a computerized, patient-interactive programmer. *Neuromodulation* 7:13–25, 2004).

TABLE 30.1. Specifications of electrodes used in a randomized trial comparing the technical and clinical outcomes of treatment with two electrode designs

	Percutaneous 3487A Pisces Quad	Laminectomy 3587A Resume
Inter-contact space (mm)	9	10
Contact length (mm)	3	4
Contact width (mm)	1.2	4
Contact area (mm ²)	11.3	12.5
Insulated	No	Yes

trodes were placed at the spinal level that had provided the best pain/paresthesia overlap during the screening trial.¹¹

Given the importance of pain/paresthesia overlap for pain relief and the importance of the amplitude setting for energy efficiency (especially before the availability of rechargeable batteries), we tested patient and computer ratings of pain/paresthesia overlap and amplitude for three standard bipole contact combinations and found that, for all three measures, the insulated electrode used in Group L significantly outperformed both the control ratings obtained with the temporary percutaneous electrode during the screening trial in Group L ($P = 0.0005-0.0047$) and the ratings obtained with the percutaneous electrode implanted for chronic use in Group P ($P = 0.0000-0.026$).¹¹

In addition, compared with the temporary percutaneous electrode, the insulated electrode provided significantly better coverage of the low back and, at subjectively identical stimulation intensities, required a significantly lower amplitude. In fact, use of an insulated electrode would double the battery life that could be expected with a percutaneous electrode.¹¹

Clinical Results

We used impartial third parties to gather clinical outcome data from this same group of FBSS patients to determine the success rate (at least 50% sustained relief of pain and patient satisfaction). At a mean follow-up period of 1.9 years, we found that 10 Group L patients and five Group P patients reported a successful outcome ($P < 0.05$). At a mean duration of 2.9 years follow-up, this result was maintained in five Group L patients and three Group P patients, which was not a statistically significant difference. Many patients reported improvement in most activities of daily living, and loss of function was rare. In addition, nine Group L patients and four Group P patients reduced or eliminated analgesic use, which was a significant inter-group difference ($P < 0.05$).¹⁴

Thus, in addition to the technical advantages it offered (lower power consumption and significantly greater pain/paresthesia overlap with standard bipole configurations), the

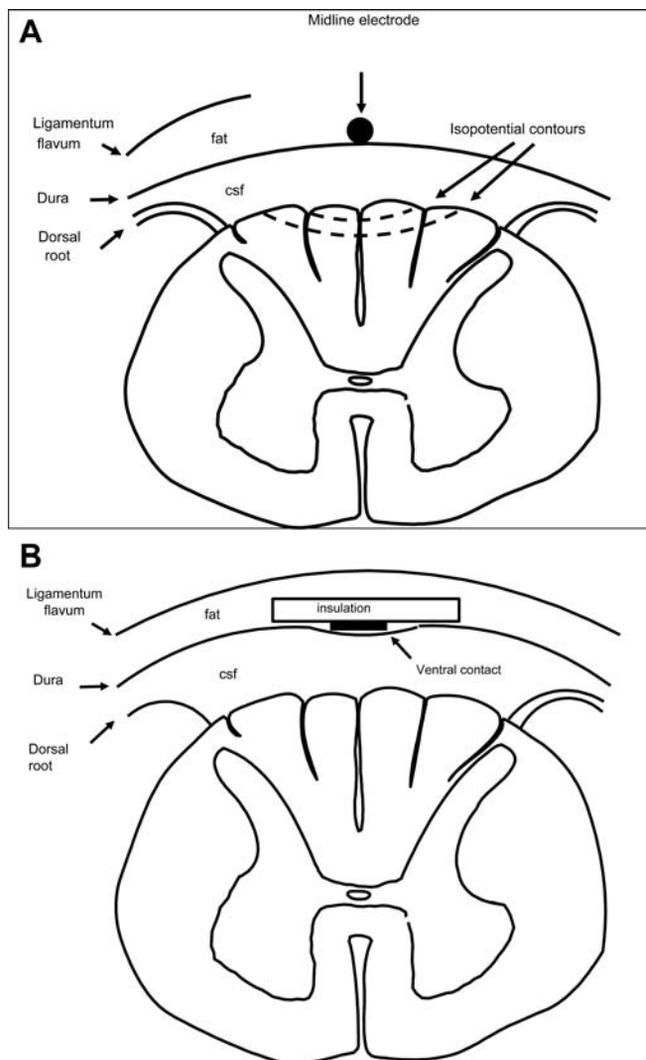


FIGURE 30.3 Cross sections of the spinal canal indicating the ideal position of a percutaneous electrode (A) and an insulated electrode (B) (redrawn from, North RB, Kidd DH, Olin JC, Sieracki JN: Spinal cord stimulation electrode design: A prospective, randomized, controlled trial comparing percutaneous and laminectomy electrodes—Part I: Technical outcomes. Neurosurgery 51:381–389, 2002).

insulated, four-contact laminectomy electrode yielded significantly better clinical results in our group of FBSS patients at mean follow-up period of 1.9 years, but the statistical significance of this clinical advantage disappeared at mean follow-up period of 2.9 years in our small sample.¹⁴

SPINAL CORD STIMULATION FOR FBSS PATIENTS WITH AXIAL LOW BACK PAIN

Our cross-over study of reoperation versus SCS had excluded FBSS patients with predominant axial low back pain because paresthesia overlap of the lower back is difficult

to achieve,³ and pain/paresthesia is a prerequisite for successful treatment. In addition, low back pain is generally thought to be mixed with a smaller neuropathic and greater nociceptive component than is radicular pain (nociceptive pain is thought to not respond as well as neuropathic pain to SCS).^{4,16}

Effectiveness of SCS for Low Back Pain

The first thing to be considered in investigating the feasibility of using SCS to treat axial low back pain is the technical effectiveness of the treatment (the extent to which SCS covers the low back with paresthesia and relieves low back pain). To this end, Barolat et al.¹ conducted a multicenter study and reported follow-up data on 41 patients at 6 and 12 months. All patients had predominant axial low back pain, as well as radicular pain in the legs. Success was defined as a patient rating of pain relief at 2 or above on a 0 to 4 scale. Using a laminectomy electrode with a total of 16 contacts arrayed in two parallel rows, the investigators achieved a six-month success rate of 91.6% for the lower back and legs and 82% for the back, and a 1-year success rate of 88.2% for the lower back and legs and 68.8% for the back.

Dose-Response Studies

The next phase of investigation focused on the dose-response; that is, how many electrode contacts are required to treat low back pain, and what is the optimum geometrical arrangement of these contacts (e.g., one percutaneous or laminectomy electrode with four contacts, one laminectomy electrode with a total of eight contacts arranged in two parallel columns, two percutaneous electrodes with four contacts each arranged in two parallel columns, etc.).

Controlled Prospective Trial of Midline versus Parallel Percutaneous Electrode Array

In our first dose-response study,¹² we tested the hypothesis that two parallel electrodes bracketing the midline with longitudinal arrays of contacts would produce a better outcome than would a single midline electrode with a single longitudinal column of contacts. A consecutive series of 20 patients who passed a screening trial with a percutaneous electrode containing four longitudinal contacts received two parallel percutaneous electrodes with four contacts each for chronic use. The dual electrode configuration was implanted at the same vertebral level that provided pain/paresthesia overlap during the screening trial (*Fig. 30.4*). In 10 of the patients, the electrodes had 10 mm contact spacing; the other 10 received electrodes with 7 mm contact spacing. The patients acted as their own controls in the comparison of the technical performance of the single versus the dual percutaneous electrodes.

Our technical outcome measures were 1) overlap of pain by paresthesia calculated according to a visual analog scale rating (0–100 mm) and according to a computerized

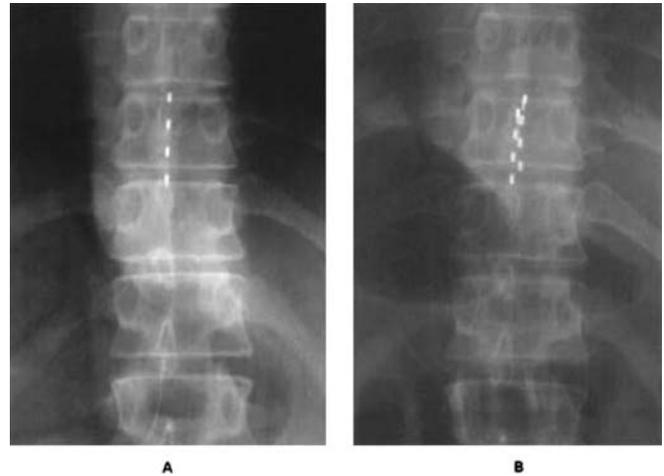


FIGURE 30.4 The dual percutaneous electrodes (*right*) bracket the midline at the same spinal level that had maximized useful pain/paresthesia overlap with the midline single percutaneous electrode (*left*). The contacts in the parallel electrodes are offset and separated by no more than one contact width (*from*, North RB, Kidd DH, Olin J, Sieracki JM, Farrokhi F, Petrucci L, Cutchis PN: Spinal cord stimulation for axial low back pain: A prospective, controlled trial comparing dual with single percutaneous electrodes. *Spine* 30:1412–1418, 2005).

rating of overlap in the pain/paresthesia drawings entered by the patient and 2) amplitude settings, both absolute (which affects battery longevity) and clinical (scaled to provide low back coverage in the usage range between perception and discomfort).

Technical Results

We found that, compared with the dual 7-mm electrodes, the single percutaneous electrode provided significant ($P < 0.01$) technical advantages. Specifically, patient ratings of overlap were 58 for the dual versus 67 for the single ($P = 0.003$), computer calculated ratings of overlap were 57 for the dual versus 65 for the single ($P = 0.007$), the amplitude requirement was 44 for the dual versus 20 for the single ($P = 0.0000$), and the amplitude for low back coverage was 64 for the dual versus 46 for the single ($P = 0.0000$). Guarded bipole stimulation (two anodes bracketing a cathode), which we have found to be advantageous in some pain conditions,⁷ offered no benefit.¹²

The short-term technical advantage of the single percutaneous electrodes compared with two 10-mm percutaneous electrodes was slight and did not reach significance except in the case of amplitude requirement. Specifically, calculated overlap was 52 for the dual versus 57 for the single, the amplitude requirement 43 for the dual versus 20 for the single (210%), the scaled amplitude for low back coverage was 53 for the dual versus 43 for the single, and, once again, guarded bipole testing offered no benefit.¹²

At the 6-month follow-up evaluation, 100% of 15 patients reported paresthesia coverage of radicular pain as did 92% of 12 patients at 2.3-year mean follow-up period. At 6 months, 73% of patients reported paresthesia coverage of axial low back pain, as did 67% at a mean 2.3 year follow-up period.¹²

Clinical Results

Using our standard procedure (data collection by a disinterested third party) and outcome measures (at least 50% pain relief and patient satisfaction), we found that, at 6 months, 88% of 16 patients reported relief of radicular pain and 50% reported relief of axial low back pain. By a 2.3-year mean follow-up period, 92% of 13 patients reported relief of radicular pain and 46% reported relief of axial low back pain. Overall, 53% of the patients reported clinical success at a 2.3 year mean follow-up period. Despite the difficulty of treating axial low back pain, this success rate is comparable with our usual SCS success rate for other conditions.¹²

Midline Percutaneous Electrode versus Laminectomy Electrode with a Parallel Array of Contacts

Our next dose-response study, also in 10 patients who acted as their own controls, compared computerized parameter measures for a temporary, four-contact, percutaneous electrode with those obtained using an implanted insulated electrode with two parallel rows of eight contacts (16 total).¹³ The percutaneous electrode resulted in marginally better patient-rated (109%, $P = 0.06$) and computer-calculated pain/paresthesia overlap (107%, $P = 0.17$), required an insignificantly higher scaled amplitude to cover the low back (106%, not significant), operated with significantly lower voltage (78%, $P = 0.0004$), significantly increased extraneous coverage (141%, $P = 0.0000$), and significantly im-

proved symmetry of paresthesia (25%, $P = 0.001$). Thus, we observed no significant technical advantage in treating axial low back pain with the insulated two-column 16-contact electrode versus a well-placed midline percutaneous electrode with four contacts, but, in some patients, the significant reduction in extraneous coverage offered by an insulated electrode could have an important clinical beneficial effect.¹³

These patients were ultimately followed clinically, and their outcomes reported, by Barolat et al.,¹ with favorable results (better, as reported, than those we observed with parallel percutaneous arrays). Differences in outcome assessment methods make this comparison difficult. We would expect some advantage for the laminectomy electrode by comparison with the percutaneous electrode, based upon our randomized controlled trial. Offsetting this, however, is the disadvantage of parallel arrays, placed intentionally with contacts on either side of the midline, as demonstrated in our controlled trials of these configurations. Computerized finite element models of the latter indicate prominent lateral recruitment, which would be expected to lead to dose limiting side effects, as shown in *Figure 30.5*.

In the future, it is foreseeable that multiple columns of electrode contacts will be shown to be advantageous if one column is on the midline. Additional columns on either side can then be used for anodal blocking. To the extent the “midline” column may be off target, laterally placed contacts may help to compensate for this. Placing all the contacts deliberately off the midline target, however, as has been done with dual column arrays, has proven to be suboptimal.



FIGURE 30.5 This finite element model indicates that, given a cerebrospinal fluid thickness of 2.6 mm or less and electrodes placed at T8–T9, a single midline cathode (*right*) will activate a deeper area with a lower amplitude laterally than will laterally-placed cathodes (*left*), which will instead increase lateral recruitment and segmental side effects (*from*, Holsheimer J, Wesselink WA: Effect of anode-cathode configuration on paresthesia coverage in spinal cord stimulation. *Neurosurgery* 41:654–60,1997).

REFERENCES

1. Barolat G, Oakley JC, Law JD, North RB, Ketcik B, Sharan A: Epidural spinal cord stimulation with a multiple electrode paddle lead is effective in treating intractable low back pain. *Neuromodulation* 4:59–66, 2001.
2. Holsheimer J, Wesselink WA: Effect of anode-cathode configuration on paresthesia coverage in spinal cord stimulation. *Neurosurgery* 41:654–660, 1997.
3. Law JD: Targeting a spinal stimulator to treat the “failed back surgery syndrome.” *Appl Neurophysiol* 50:437–438, 1987.
4. Meyerson BA: Electric stimulation of the spinal cord and brain, in Bonica JJ, Loeser JD, Chapman RC, Fordyce WE (eds): *The Management of Pain*. Philadelphia, Lea & Febiger, 1990, ed 2, pp 1862–1877.
5. North RB, Campbell JN, James CS, Conover-Walker MK, Wang H, Piantadosi S, Rybock JD, Long DM: Failed back surgery syndrome: 5-year follow-up in 102 patients undergoing repeated operation. *Neurosurgery* 28:685–690, 1991.
6. North RB, Ewend MG, Lawton MT, Kidd DH, Piantadosi S: Failed back surgery syndrome: 5-year follow-up after spinal cord stimulator implantation. *Neurosurgery* 28:692–699, 1991.
7. North RB, Ewend MG, Lawton MT, Piantadosi S: Spinal cord stimulation for chronic, intractable pain. Superiority of “multichannel” devices. *Pain* 44:119–130, 1991.
8. North RB, Fowler KR: Computer-controlled, patient-interactive, multichannel, implanted neurological stimulators. *Applied Neurophysiology* 50:39–41, 1987.
9. North RB, Kidd D: Cost-efficacy of spinal cord stimulation vs. reoperation for failed back surgery syndrome: A randomized controlled trial.

- Neuromodulation** 9:12, 2006 (abstr).
10. North RB, Kidd DH, Farrokhi F, Piantadosi S: Spinal cord stimulation versus repeated lumbosacral spine surgery for chronic pain: A randomized, controlled trial. **Neurosurgery** 56:98–106, 2005.
 11. North RB, Kidd DH, Olin JC, Sieracki JN: Spinal cord stimulation electrode design: A prospective, randomized, controlled trial comparing percutaneous and laminectomy electrodes—Part I: Technical outcomes. **Neurosurgery** 51:381–390, 2002.
 12. North RB, Kidd DH, Olin J, Sieracki JM, Farrokhi F, Petrucci L, Cutchis PN: Spinal cord stimulation for axial low back pain: A prospective, controlled trial comparing dual with single percutaneous electrodes. **Spine** 30:1412–1418, 2005.
 13. North RB, Kidd DH, Olin J, Sieracki JN, Petrucci L: Spinal Cord Stimulation for Axial Low Back Pain: A Prospective, Controlled Trial Comparing 16-Contact Insulated Electrode Arrays with 4-Contact Percutaneous Electrodes. **Neuromodulation** 9:56–67, 2006.
 14. North RB, Kidd DH, Petrucci L, Dorsi MD: Spinal cord stimulation electrode design: A prospective, randomized, controlled trial comparing percutaneous with laminectomy electrodes. Part II. Clinical outcomes. **Neurosurgery** 57:990–996, 2005.
 15. North RB, Nigrin DA, Fowler KR, Szymanski RE, Piantadosi S: Automated ‘pain drawing’ analysis by computer-controlled, patient-interactive neurological stimulation system. **Pain** 50:51–57, 1992.
 16. Sanchez-Ledesma MJ, Garcia-March G, Diaz-Cascajo P, Gomez-Moreta J, Broseta J: Spinal cord stimulation in deafferentation pain. **Stereotact Funct Neurosurg** 53:40–55, 1992.
 17. Waddell G, McCulloch JA, Jummel EG, Venner RM: Non-organic physical signs in low back pain. **Spine** 5:117–125, 1980.