Dorsal column stimulation for control of pain

Preliminary report on 30 patients

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✓ Thirty patients with chronic intractable pain have had dorsal column implants and a trial of subsequent electrical self-stimulation to relieve the pain. Burning pain originating from damage to the CNS was most often relieved, while chronic bone, joint, and disc pain responded less well. Patients with severe psychiatric factors should be excluded, but preoperative selection is still difficult because of the lack of objective clinical tests. The long-term effect of the implant on the tissues of the dorsal column is still unknown and requires further evaluation. Although relief of pain has been reported for as long as 3 years, much longer follow-ups are necessary to evaluate the efficiency of this system in patients with chronic pain. Direct stimulation of the spinal cord raises a number of interesting questions in regard to perception and sensory phenomena in man but, as yet, there are no answers as to how dorsal column stimulation effects its relief of pain.

KEY WORDS · dorsal column stimulation · pain · electrodes

THE application of surface electrodes to the dorsal columns of the spinal cord has been used by Shealy, *et al.*,[6] and Sweet and Wepsic[7] in the treatment of intractable pain. The rationale for dorsal column stimulation (DCS) has been the "gate theory" of pain proposed by Melzack and Wall.[3] Stimulation of large diameter myelinated peripheral cutaneous fibers or of their extensions into the dorsal columns will inhibit some of the activity produced in dorsal horns by stimulation of small myelinated or unmyelinated fibers. We have carried out the implantation of DCS in 30 patients and studied its effects on chronic pain.

Clinical Material

Thirty patients (17 males and 13 females) were followed for periods of 9 to 18 months; their ages ranged from 14 to 61 years. The duration of chronic pain varied from 8 months to 30 years; the etiologies of the pain are summarized in Table 1. The pain was centered in the lower back or legs in most of the patients. Many of the patients had had previous surgery performed for ruptured intervertebral discs or unstable spine, and had undergone multiple operative procedures for relief of back pain including laminectomies, fusions, discectomies, and in some cases, either open or percutaneous cordotomy. Often the pain had changed its original character from a severe radicular pain characteristic of nerve root involvement to a generalized burning pain involving the back and legs. All of the patients were receiving high doses of analgesics and in 13, narcotics were being used. Three patients had sus-

TABLE 1

Summary of DCS in 30 patients

Case No.	Etiology of Pain		Locus of Pain	Duration of Pain	Pain Relief with DCS*
	Primary Pathology	Neurological Deficit			
1	spinal fracture	transient paraplegia	leg	23 yrs	C
2	spinal fracture	complete paraplegia	leg	19 yrs	D*
3	spinal fracture	complete paraplegia	leg	1 yr	B
4	spinal fracture		leg	6 yrs	C
5	spinal fracture†		leg	11 yrs	A
6	spinal GSW‡	complete paraplegia	leg	9 yrs	C
7	lumbar HNP—spinal fusion†‡		leg	2 yrs	B
8	lumbar HNP—spinal fusion		leg	2 yrs	C
9	lumbar HNP—spinal fusion		leg	9 yrs	C
10	lumbar HNP—spinal fusion		leg	7 yrs	D
11	lumbar HNP—spinal fusion		leg	10 yrs	D*
12	lumbar HNP—spinal fusion		leg	2 yrs	A
13	lumbar HNP—spinal fusion†		leg	8 yrs	D
14	lumbar HNP—spinal fusion		leg	5 yrs	D*
15	lumbar HNP—spinal fusion		leg	13 yrs	D*
16	lumbar HNP—spinal fusion		leg	6 yrs	A
17	lumbar HNP—spinal fusion		leg	4 yrs	D*
18	progressive scoliosis, spinal fusion		leg	30 yrs	A
19	spinal cord contusion	transient Brown-Séquard	leg	7 mos	D
20	avulsion brachial plexus	complete motor and sensory loss	arm	1 yr	B
21	avulsion brachial plexus	complete motor and sensory loss	arm	8 mos	D
22	avulsion brachial plexus§	complete motor and sensory loss	arm	6 yrs	A
23	stretch brachial plexus	no deficit	arm	6 yrs	A
24	GSW arm	multiple peripheral nerve involvement	arm	1 yr	A
25	minor leg trauma		leg	9 mos	D*
26	liver varices, multiple laparotomy		abdomen	8 yrs	D
27	multiple sclerosis	motor and posterior column deficit	leg	14 mos	D*
28	Caisson disease	transient paraplegia	leg	2 yrs	A
29	herpes zoster	thoracic dysesthesia	chest	4 mos	A
30	cancer, rectum		pelvis	4 mos	D

* A = excellent; B = good; C = fair; D = poor; D* = DCS removed.
† Cordotomy. Follow-up 9 to 18 months.
‡ HNP = herniated nucleus pulposus; GSW = gunshot wound.
§ Mesencephalotomy.

tained brachial stretch injuries with root avulsion which was demonstrated by myelography in two; at operation for the placement of the DCS, the spinal cords were found to be atrophic on the side of the avulsed roots, suggesting that the pain was of central origin.

The cases with a traumatic etiology included six patients with spinal fractures; two of these were permanently and one transiently paraplegic. Another patient was permanently paraplegic due to a spinal gunshot wound; another patient sustained a Brown-Séquard syndrome during an anterior spinal fusion. In one of these patients, an open cordotomy had been done.

Of the patients with prior history of ruptured intervertebral disc or unstable lumbosacral spine, there was a patient who had been rendered transiently paraplegic, and in this group of patients two had had either an open or percutaneous cordotomy. Caisson disease with the "bends" occurred in a diver and he was transiently paraplegic after the dive due to an improper decompression; after a time he did recover motor function but then developed intermittent intractable pain in both legs.

In another group of patients with pain due to trauma to an extremity, the injuries included a shotgun wound of the arm resulting in the loss of the forearm; an auto accident

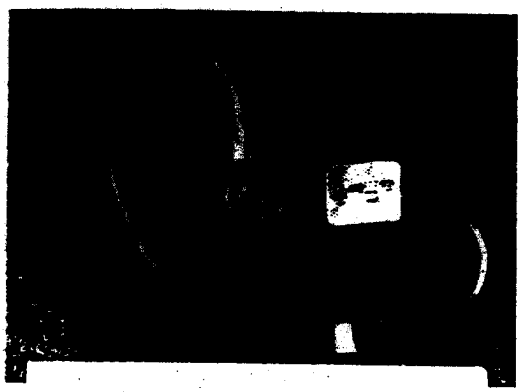

FIG. 1. DCS equipment with four platinum electrodes used for bilateral dorsal column stimulation.

resulting in the loss of the right leg; and a blunt injury to the soft tissues and bone of the ankle. One patient with leg amputation had undergone a stereotaxic mesencephalic tractotomy with partial relief of his pain.

The pain was described as either severe aching, "bone crushing," or "dull aching" in 16 patients, while 14 patients described a "burning pain"; in four of the patients pain was exacerbated by the slightest pressure or touch. Neurological deficits were demonstrated in 21 patients. There were three who had permanent paraplegia while three other patients had a history of transient paraplegia with near total recovery but some clinical evidence of mild motor or sensory deficits.

Psychiatric disturbances were present in 13 patients, and their psychological state was thought to be exacerbated by the presence of the pain. Varying degrees of depression were noted with suicidal tendencies in three patients. Marked euphoria was noted in one patient with multiple sclerosis; however, it was difficult to correlate the onset of the psychiatric disturbances with the chronicity of the pain syndromes.

The preoperative evaluation consisted of history and physical examination including neurological evaluation, roentgenograms, myelography, urological evaluation in some including cystometrogram and intravenous pyelograms, electromyograms, and, in addition, psychiatric evaluations were obtained in most patients.

Operative Procedure

The electrical stimulus was delivered by implanted bilateral electrodes with four platinum discs affixed to a thin footplate of silicon-coated Dacron mesh connected to a miniature rf receiver (Fig. 1). Repetitive stimulation was delivered either to both posterior columns or by using a unilateral DCS electrode with two platinum discs in tandem; one dorsal column was activated. Electrical stimulation was supplied by a miniature battery-powered radiotransmitter which produced a square wave of variable frequency, voltage, and pulsewidth coupled by means of a flexible antenna.* Voltage could be varied from 0.3 to 30V frequency from 9 to 550 cycles/sec and pulsewidth from 100 to 800 μsec. The patient was instructed in the basic use of the voltage and frequency controls but the levels of stimulation were determined by the patient as he used the device.

The operation consisted of a laminectomy at least two to four spinal segments above the highest dermatomal level of the patient's pain (Fig. 2). For pain in the lower part of the body, the electrode was placed at the mid- or high-dorsal region, and for chest or arm pain it was placed in the cervical region

* DCS equipment was made by Avery Laboratories, Inc., 145 Rome Street, Farmingdale, New York.

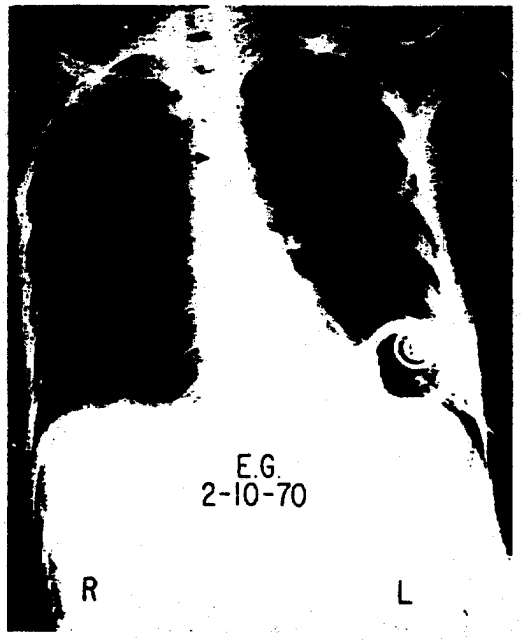

FIG. 2. Roentgenogram of patient with bilateral thoracic DCS. Subcutaneous rf receiver and external antenna seen on left. *Arrow* indicates contacts on DCS implant.

FIG. 3. *Left:* Drawing of cross section of spinal cord showing the DCS plate resting on the dorsal column separated by a thin layer of arachnoid. *Right:* Drawing of dorsal view of spinal cord with DCS plate positioned over the dorsal columns with anchoring sutures.

at C-3 or C-4. A counter incision was placed in the left side of the chest along the anterior axillary line for the thoracic implant where the rf receiver was buried subcutaneously with the connecting wires passed subcutaneously to the iaminectomy site. For cervical implantation the rf receiver was placed subcutaneously in the subclavicular region. The stimulation plate was placed beneath the dura but external to the arachnoid and internally sutured through the dura to allow the platinum electrodes to rest gently on the dorsal surface of the cord without exerting excessive pressure (Fig. 3a). A purse-string suture was placed around the opening in the dura where the cable passed through, and the dura was tightly closed. Six unilateral and 24 bilateral electrodes were implanted. Seven of the electrodes were placed in the cervical region for arm pain, and the remainder were placed in the thoracic region for low back and leg pain.

On the seventh postoperative day self-stimulation was begun, and detailed notes made concerning the effect of DCS on the patients' pain, as well as the kinds of sensation evoked by the dorsal column activation. Any changes in the neurological function during DCS stimulation were noted and any change in the patients' requirement for drugs recorded.

Results

A total of 26.7% of the patients have had excellent relief of pain, another 13.3% have had good relief, 16.7% have had only a fair result, and 43.3% have been classed as failures. A result was judged "excellent" when the patient had complete relief of chronic pain and was able to withdraw all medications. A patient with a "good" result had only mild pain requiring small amounts of analgesics. The patients with "fair" results experienced definite but limited improvement and still required analgesics. A "poor" result indicated no relief.

There have been nine failures and, of these, seven patients have had the electrode removed and in none of these patients was there ever definite relief obtained even after repeat operations to reposition the electrode. It should be noted that at least five of these failures were in patients with long-term psychiatric disorders. Thus, the overall rate of failure of the DCS was exaggerated. One patient with pain associated with a carcinoma of the rectum who was considered a failure using the DCS, died 1 month after implantation. The effects of early postoperative stimulation did not reliably predict the ultimate success or failure of the DCS. In 16 of the patients the effects have not changed while eight others have noted later improvement;

in six patients the effectiveness of stimulation has decreased.

Each patient could distinguish between the effects of the voltage and frequency used for stimulation. Marked increase in the levels of voltage were not tolerated as well as changes in the frequency of the stimulus. With both dial settings at zero of the rf generator, the minimal level of voltage can be increased to about 4 V at which point the evoked sensation becomes intolerable. The sensation of dc activation was usually described as a "thumping" at the lower frequencies and this sensation gradually changed to a sense of vibration as the frequency was increased to 40 cps. When the frequency was increased above 50 cps, the patients usually described a waxing and waning, continuous wave-like sensation, and with a frequency above 150 to 200 cps all evoked sensation generally was abolished, regardless of the voltage and whether or not the stimulation abolished pain.

The best range of stimulation parameters that produced relief of pain was from 0.5 to 3V at 15 to 200 cps with a 200 μsec pulse width stimulus. A number of patients preferred ranges of stimulation between 40 to 50 cps for best relief of pain. Except in rare instances, stimulation of the dorsal column had no effect on the patients' subjective ability to perceive sensation (pain, touch, proprioception, or vibration), and this was true whether the patient was normal neurologically or exhibited minor degrees of sensory impairment. Those patients, however, who previously were paraplegic or had been paraparetic, or had had a previous anterolateral cordotomy, seemed to obtain better pain relief using the DCS. Most of the patients described a sensation resembling either a vibration or mild electric shock, usually referred to levels below the site of the electrode. Some patients with the DCS in the thoracic region experienced paresthesia referred into the arms and ulnar aspect of the hands. Pain relief occurred only if the paresthesia produced by the DCS was referred into the involved painful area. There was no impairment of motor function noted during stimulation. There were several patients in whom bladder sensation was either augmented or inhibited during the DCS.

The patients differed widely in the amount of stimulation required to obtain pain relief. Some have had excellent relief with a constant stimulation during the waking hours, while others have required intermittent periods of stimulation lasting from 15 to 60 minutes with the pain relief outlasting the stimulation for from 1 to 5 hours. It was of interest that the acute pain in the immediate postoperative period was not relieved by the dc stimulation.

Complications

In the immediate postoperative period 17 patients experienced an unusual degree of incisional and radicular pain lasting for 10 to 14 days.

There were five patients in whom a total of six operations were performed to correct a subcutaneous cerebrospinal fluid (CSF) leak which manifested itself by subcutaneous swelling along the electrode cable and around the rf receiver.

Five patients underwent reoperation for repositioning of either the electrode footplate or the receiver. In three patients, two of whom had previously obtained excellent relief from pain followed by a period of time when the effect of the DCS diminished, we found at reoperation marked thickening of the arachnoid beneath and around the stimulation plate. Relief of pain occurred in two patients after we repositioned the electrode, placing it beneath the arachnoid. One obese patient experienced good relief after his receiver was reimplanted and anchored closer to the skin surface. Defective electrodes were replaced in two patients with continued good relief of pain. Three patients experienced skin erosion or cellulitis due to excessive pressure of the external antenna over the subcutaneous receiving button but with conservative skin care the condition improved, and there were no patients with subcutaneous infection or meningitis.

The most serious postoperative complication occurred in three patients who developed motor deficits postoperatively. One patient exhibited a Brown-Séquard syndrome while two were transiently paraplegic. All recovered completely, however, when the DCS was removed, and no disabling symptoms have resulted. The DCS was reimplanted 2

weeks later in the patient who developed the Brown-Séquard syndrome; he has experienced excellent relief of pain for 15 months. It seems obvious that the stimulating plate must not exert pressure on the spinal cord and great care must be exercised by the surgeon when it is fixed beneath the dura.

Discussion

Our observations confirm those of Shealy, *et al.*,[6] and others[1,7] that electrical stimulation of the dorsal aspect of the spinal cord will relieve certain kinds of pain. The overall good results in our series are somewhat less than those reported by Shealy, *et al.*[6] This may have been due to the inclusion of the patient with severe psychiatric disturbance, a type Shealy, *et al.*, have recently eliminated by the MMPI test. The most satisfactory relief occurred in patients in whom the pain was described as burning in nature and who exhibited clinical evidence of previous injury to the CNS, with some degree of neurological involvement of the sensory pathways. On the other hand, pain originating from either an osseous or muscular source was not as significantly relieved in our group of patients. There appears to be some difference in relief whether the pain is central or peripheral in origin although Wall and Sweet[7] have reported some success with stimulation of painful peripheral nerves. A patient with burning pain originating from a central lesion seems to have the best chance of obtaining relief by the DCS, and this strongly suggests a central neural mechanism activated by the stimulation via the dorsal column system.

According to the "gate theory" of Melzack and Wall,[3] the pain relief which follows peripheral nerve stimulation, as used by Wall and Wepsic, is due to inhibition of the small myelinated or unmyelinated fibers by electrically activating the large myelinated fibers.[6,7] In animal experiments, the site of this inhibition seemed to be the cells in the substantia gelatinosa of the dorsal horns at the level of the stimulation. The neural mechanism responsible for relief of pain by direct dorsal column stimulation may be due, as Hillman and Wall[2] have suggested, to antidromic impulses generated by the DCS which enter the dorsal horns via collaterals from the dorsal column fibers to produce inhibition.

One question of importance in regard to stimulation of the dorsal aspect of the cord is the extent to which the spinal cord can be activated by the electrical current. It seems to us that the stimulation may be limited to the dorsal columns since any spread of current beyond it to involve the nearby spinocerebellar pathways might have caused motor or cerebellar symptoms that were not noted in our patients. During DCS some patients could easily distinguish slight reductions of proprioceptive sensation in their feet, yet they could perceive the sharpness of a pinprick in the same area; this suggests involvement of proprioception alone. Nathan and Smith[4] have presented clinical evidence that the dorsal columns carry touch and pressure sensation from the urethra; we noted that bladder sensations produced by filling could either be suppressed or augmented during dorsal column activation. The spread of the current in the spinal cord is still not understood.

The relief of pain was always associated with a "buzzing" sensation or paresthesia referred into the painful area of the body. The localization of the paresthetic sensation was definitely related to the position of the DCS on the surface of the spinal cord activating the appropriate fibers in the dorsal column. There is a definite anatomical arrangement of the afferent fibers in the dorsal column; fibers transmitting impulses from the caudal portions of the body lie medial to the fibers carrying impulses from the cervical segments.[5] Therefore, it was important to place the DCS in such a position on the dorsal surface of the cord as to produce the referred paresthesia in the appropriate segments of the body. The most satisfactory effect for the arm was the placement of the DCS about 2 mm off the midline on the dorsal aspect of cervical cord toward the side of the arm pain. Paresthesia referred into the leg was commonly reported with stimulation of the thoracic cord at T-3 to T-5, but the perineal and rectal regions, as well as the anterior aspect of the lower abdomen, may be spared. This suggests that at higher thoracic levels the fibers carrying impulses from the sacral and abdominal segments of the body lie

deeper within the dorsal column. An alternate explanation of the difficulty activating the sacral and lower abdomen regions could be related to a greater volume of the fibers in the dorsal column which are devoted to the representation of the extremities and, especially, the distal parts of the limb.[5] Adams[1] has recently carried out percutaneous stimulation of the dorsal columns prior to implantation of the DCS and noted a definite homunculus at the cervical level of the dorsal column with the trunk and sacral regions lying deep to the more superficial cervical segments. This was an important step in our understanding of the topography of the dorsal column in man.

The method of patient selection remains crucial for the success or failure of any new operative procedure, and this is particularly true when sensation and pain must be assessed subjectively. At present there are no objective preoperative tests that can be used to select patients for the DCS. We believe that patients with burning pain of central origin have at least a 50% chance of relief if the patient does not have severe psychological involvement. A patient who is severely depressed may be relieved of pain but will still require postoperative psychiatric therapy. Patients addicted to narcotic drugs for long periods of time do not appear to be suitable candidates for surgery. Shealy, *et al.*,[6] have used the MMPI test to eliminate hysterical and severely depressed patients, and Adams[1] has used a preoperative percutaneous stimulation of the cord to give the patient an idea as to the kind of sensation produced by the DCS. Several of his patients who were unable to tolerate the electrical paresthesias were not selected for surgery.

The operation was not without some serious postoperative morbidity which included transient paresis of the legs, chronic radicular pain, and the subcutaneous seepage of CSF around the receiver button. Fortunately in none of the patients was the postoperative paresis permanent or disabling and all patients recovered when the DCS was removed. It was also interesting that two of the three patients who did develop postoperative motor weakness had exhibited preoperative evidence of spinal cord motor dysfunction. Perhaps this type of patient should not be chosen for the operation. Radicular pain noted during DCS stimulation was thought to be due to activation of the dorsal roots adjacent to the site of the implant on the cord, and this complaint has recently been eliminated by sectioning the dorsal root filaments adjacent to the DCS. The leakage of the CSF that occurred along the wires at exit points in the dura has also been corrected by placing a purse-string suture at this point, plus closing the dura tightly.

An essential question in regard to the long-term use of the DCS is the tolerance of the tissues to the implant. In general the DCS seems to be well tolerated in the subcutaneous and muscular tissue for at least the first 3 years after implantation. Thickening of the arachnoid occurred in some of our patients when the stimulating plate was placed intradurally and extra-arachnoidally, and any thickening of the arachnoid could possibly interfere later on with the efficiency of the DCS stimulation. Reexploration of the DCS in several of our patients revealed that this arachnoidal thickening had involved the adjacent nerve roots and was responsible, perhaps, in several patients, for the radicular pain which was corrected by sectioning the involved roots. Recently we have changed our surgical technique by placing the stimulating plate in the subarachnoid space where the DCS is in direct contact with the dorsal surface of the cord. On reexploration in one patient after 3 months we found little or no arachnoidal response on the surface of the cord, and the dorsal vessels on the cord appeared normal. What the long-term effect of DCS implant might be are as yet not known, and no pathological examination of spinal cords has been carried out in patients with long-term implants.

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