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High-Dose Spinal Cord Stimulation for Treatment of Chronic Low Back Pain and Leg Pain in Patients With FBSS, 12-Month Results: A Prospective Pilot Study

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Objectives: To investigate the long-term effect of high-dose spinal cord stimulation (HD-SCS) in patients with chronic refractory low back and leg pain due to failed back surgery syndrome (FBSS).

Study Design: Prospective case series; pilot study.

Materials and Methods: Patients with chronic low back and leg pain (CBLP) due to failed back surgery syndrome (FBSS) were screened for SCS according to the Dutch Neuromodulation Society guidelines. Patients with a pain score of >50 (on a visual analogue scale from 0 to 100) for both low back and leg pain, were selected for participation in this study.
During intraoperative screening one or two electrodes were implanted to ensure adequate paresthesia coverage of the back and leg pain area.
During the 14 days trial period patients received two programs: a conventional or low-dose (LD) program with 30 Hz; 390 μsec and a high-dose (HD) program with 420 Hz, 400 μsec. They all started with LD-SCS and changed to HD-SCS after three days. If patients reported more than 50% pain relief with either program a rechargeable neurostimulator was implanted for permanent SCS.
The scores for low back pain and leg pain were recorded separately. Other therapy related outcomes that were collected are pain medication use, Quebec back pain disability scale (QBPDS), patient satisfaction, employment status, stimulation settings, and adverse events. We present the 6- and 12-months results. Results are presented as mean ± SD.

Results: Thirteen patients, nine females and four males (mean age: 49.7 ± 8.1 years), were included between July 2015 and March 2016. Eleven patients responded to SCS during the trial period and were implanted with a neurostimulator. Most patients preferred HD-SCS over LD-SCS and the overall use of HD-SCS increased over time.
At 6 to 12 months follow-up, two patients discontinued the study. In one patient low back pain returned despite optimal stimulation settings. The second patient was neither satisfied with LD nor HD and had the system explanted.
VAS Leg pain at baseline was 71.2 ± 33.8 and reduced to 25.7 ± 24.0 at 6 months and 23.4 ± 32.0 at 12 months. VAS Back pain at baseline was 66.7 ± 33.2 and reduced to 36.8 ± 41.6 at 6 months and 26.1 ± 33.2 at 12 months.
Pain medication was significantly reduced and QBPDS improved from 59.2 ± 12.2 at baseline to 44.1 ± 13.7 at 12 months. Five patients returned to work and overall patient satisfaction at the end of the study was high.

Conclusion: This pilot study shows promising results of offering HD-SCS in addition to LD-SCS for treatment of chronic back and leg pain in patients with failed back surgery syndrome.

Keywords: chronic Back and leg pain, duty-cycle, failed Back surgery syndrome, high-dose, leg pain, low back pain, low-dose, neuromodulation, spinal cord stimulation

Conflict of Interest: No conflicts to disclose.

INTRODUCTION

Conventional SCS is considered an effective long-term therapy for patients with chronic back and leg pain (CBLP) due to failed back surgery syndrome (FBSS) (1,2). In conventional SCS frequencies between 30 and 100 Hz are common in combination with a pulse duration around 210 to 390 μsec. When considering the percentage of time in which the signal is active and delivering energy at these stimulation parameter ranges, the proportion of "on" vs. "off" time (termed "duty-cycle") in conventional SCS is about 2% (3). Conventional SCS is most often used at stimulation amplitudes at which the patient feels tingling sensation in the painful area. Although

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Table 1. Pain Scores for Leg and Back (VAS: 0-100 mm).

Patient	Baseline		3 months		6 months		12 months	
	Leg	Back	Leg	Back	Leg	Back	Leg	Back
1	51	52	20	22	35	36	31	44
2	79	80	31	24	32	20	25	35
3	69	66	60	46	2	26	8	9
4	53	57	13	17	14	24	18	13
5	78	64	35	50	72	67	-*	-
6	89	77	3	4	11	8	4	9
8	71	79	3	64	5	72	-	-
9	78	71	29	28	44	45	45	47
10	86	74	20	30	14	20	9	7
11	65	52	5	5	8	4	7	6
12	64	62	18	52	46	83	64	65
Mean (SD)	71.2 (33.8)	66.7 (33.2)	21.5 (11.0)	31.1 (26.1)	25.7 (24.0)	36.8 (41.6)	23.4 (32.0)	26.1 (33.2)

* Explanted due to loss of effect.

conventional SCS provides adequate long-term pain relief, in some patients the effect of SCS on back pain diminishes despite reprogramming the paresthesia field. Sustained paresthesia coverage for the back-pain area is difficult to achieve due to the anatomical position of the large myelinated fibers in the dorsal column. As a result, conventional stimulation is often inadequate to reach and cover the lumbar pain area. Clinical studies have shown the effect of conventional SCS in neuropathic pain, but it is less effective in treating combined neuropathic and nociceptive low back pain in FBSS (4,5).

In recent years alternative SCS modes using kilohertz and burst stimulation have become available. Compared to conventional SCS these new stimulation paradigms use higher frequencies and/or longer pulse durations and as a result have duty-cycles, ranging from 9 up to 30% (3). Although most of these new stimulation modes use amplitudes that are lower than used in conventional SCS and often preventing generation of paresthesias, the total charge delivered per unit time, or "charge per second" is up to ten times that used in conventional SCS[3]. Conventional SCS could therefore be considered a "low dose" (LD) option. In contrast, higher frequencies and wider pulse widths enable higher duty-cycles, or a "high dose" (HD) option. A number of clinical studies have shown positive long-term effects with these new HD-SCS modes, that is, with varying kilohertz frequency and pulse duration settings, in patients with CBLP naïve to SCS and who lost efficacy of SCS with conventional or other kilohertz settings (6–9). When considering the duty-cycle and the total electrical charge per unit time as main determinant for the effect of HD-SCS for treatment of CBLP, in the present study we opted for a stimulation frequency of 420 Hz and a pulse width of 400 μs (ie, a duty-cycle of 16.8%), based on our earlier outpatient HD-SCS experiences.

GOAL AND MOTIVATION

In this study, we investigated the long-term effect of offering both LD-SCS and HD-SCS in FBSS patient with low back pain and leg pain.

Our motivation that led to this study was the number of patients we see in our outpatient pain clinic who suffer from chronic low back and leg pain following back surgery (FBSS). In these patients we often saw that pain became a social and economic problem and an effective therapy to treat the pain long-term was therefore highly needed.

The second reason was to explore the new technological possibilities of SCS that have become available. Currently, patients with CBLP can choose between conventional, kilohertz, Burst, and DRG stimulation. In case of low back pain only, also subcutaneous stimulation or peripheral nerve field stimulation (PNFS) can be applied (10,11).

Various studies have shown good clinical outcomes with all these neuromodulation paradigms (12–17). Otherwise, conventional SCS has shown value in patients who failed on kilohertz SCS (9).

Despite these new therapy options, in the outpatient clinic we see a significant number of patients who still suffer from low back pain after using the above stimulation modalities. To investigate whether offering different stimulation settings, including conventional (LD) and HD-settings, would be of benefit to these patients, we have set-up this prospective case-series allowing individual patient experience analysis.

METHODS

Patient Selection

Thirteen patients (9 females and 4 males), mean age 49.7 $\pm$ 8.1 years, were included in this study. Patients suffering from chronic low back and leg pain (CBLP) due to FBSS for a minimum of 12 months were included and treated with SCS in accordance with the Dutch Neuromodulation Society (VvNN) guidelines. The number of low back surgeries varied from 1 to 4, including herniated disc surgery, spondylodesis, and lumbar stenosis.

All patients had experienced failed nerve blocks, multiple pain medication regimens, TENS, physiotherapy and in some cases a rehabilitation program. All underwent a physical examination and psychological screening prior to SCS.

Before starting SCS we collected separate pain scores of low back pain and leg pain (Table 1), but also the most intense back pain area which patients wished to have treated (Table 2). This was expressed by the patients as the percentage of low back pain of total FBSS pain (low back pain plus leg pain); where the low back is defined as the area above the buttock and beneath lumbar 1 level. Most patients described a band of pain just above the buttock radiating to the flank(s) and was assessed with the patient in the upright, standing position.

The mean low back component was 45.4% $\pm$ 9.7%.

From the 13 patients, 11 patients had low back pain and unilateral leg pain. Two patients had low back pain in combination with bilateral leg pain.

Table 2. Patient Demographics.

Patient	Sex	Age (years)	Indication/spine surgical history	Low back component* (%)	Back pain size: width, height, area (cm, cm, cm^2)†
1	M	38	FBSS/2 herniated disc surgeries, L5-S1	50	10, 4, 40
2	F	44	FBSS/herniated disc surgery, L4-L5	50	17, 10, 170
3	F	40	FBSS/4 back surgeries, laminectomy L2-L5	40	16, 21, 336
4	F	47	FBSS/2 herniated disc surgeries, L4-L5	20	7, 6, 42
5	F	46	FBSS/herniated disc surgery, L5-S1	50	13, 7, 91
6	M	51	FBSS/herniated disc surgery, L5-S1	40	20, 8, 160
7	F	50	FBSS/herniated disc surgery L5-S1 and laminectomy L3-S1	60	10, 9, 90
8	M	52	FBSS/4 back surgeries, for example, spondylodesis L4-S1, material removed	40	17, 18, 306
9	F	52	FBSS/spondylodesis L4-S1	40	17, 10, 170
10	F	43	FBSS/herniated disc surgery, L4-L5	50	18, 11, 198
11	F	67	FBSS/herniated disc surgery, L3-L4 and L4-L5	50	16, 8, 128
12	M	55	FBSS/laminectomy L3-L5	50	12, 10, 120
13	F	61	FBSS/herniated disc surgery, L5-S1	50	11, 6, 66
Mean (SD)		49.7 (8.1)		45.4 (9.7)	

* Percentage of low back pain of total FBSS pain (leg pain + back pain = 100%).
† Most intense back pain area that the patient wants treated.

The study had received local IRB approval and all patients signed informed consent prior to inclusion in this study.

Study Design

Patients were included between June 2015 and March 2016 and were scheduled for a SCS trial phase following the flow chart shown in Figure 1.

For the SCS procedure we used the percutaneous technique together with fluoroscopy. The para-spinal approach was at level Th12-L1 or L1-L2. An 8-polar electrode was slowly inserted into the epidural space and located at the thoracic level. The final location of the electrode was determined by intraoperative stimulation in order to cover the whole pain area with paresthesias. In three patients, we were unable to cover the pain area with one electrode only despite varying stimulation contacts and stimulation parameters combinations and having explored the levels from Th7 to Th12. In these three cases, in accordance with the Dutch SCS-protocol, a second electrode was placed. The combination of two electrodes successfully covered the low back pain and leg pain areas in these patients.

In case electrical stimulation provided at least 80% coverage of the pain area, the leads were anchored and attached to an externalized cable for trial stimulation. Eleven of the twelve patients who received intraoperative testing reported full coverage of the pain area.

The trial period lasted 14 days during which patient received two programs (called "*Groups*"):

- Program A (LD): frequency between 30 and 100 Hz, pulse width: 390 µsec, amplitude between 2 and 8 Volt (ie, a duty-cycle between 1.2 and 3.9%).
- Program B (HD): using the same electrode configuration, a frequency of 420 Hz and a pulse width of 400 µsec, amplitude between 1 and 5 Volt (ie, a duty-cycle of 16.8%).

All patients started with program A and after three days switched to program B. The stimulation amplitude was adjusted to a comfortable level. With HD-SCS all patients used an amplitude that prevented generation of paresthesias.

The patients were instructed how to use the LD and HD stimulation modes and how to switch between programs. Patients were also informed that we would evaluate the HD-SCS therapy as an additional option for treatment of their chronic pain.

All patients visited the outpatient clinic twice during the trial period to evaluate the pain relief and if necessary, reprogram the

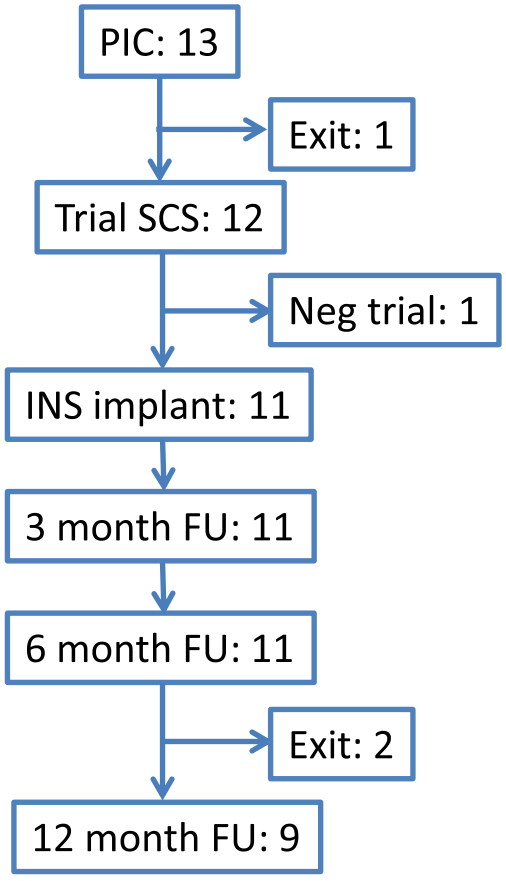

Figure 1. Flow diagram patients. [Color figure can be viewed at wileyonlinelibrary.com]

stimulation settings. During these visits the bandage of the wounds were inspected and changed if necessary.

The IPG was implanted if patients at the end of the trial period reported a pain reduction of 50% or more for low back pain and leg pain with either LD or HD stimulation.

We implanted the rechargeable neurostimulator in the upper part of the left buttock.

The location of the neurostimulator was discussed with the patient in the preparation phase of the operation. In all patients this location was not within the original pain area and patients felt no pain at the implant location.

The follow-up after implantation of the neurostimulator was at 3, 6, and 12 months at the outpatient clinic. At each visit patients responded to several questionnaires, which were thoroughly reviewed by the study nurse. The following questionnaires were used:

Pain was measured using a 100-points VAS scale. Three times daily the patient had to place a mark on a 100-mm line corresponding to their pain level (0: no pain and 100: worst pain). Average pain scores were calculated for low back and leg pain separately.

Disability was measured with the Quebec Back Pain and Disability Scale, which gives information about the effort taken (scale 1-5) to complete an activity.

Quality of life was measured with the EQ-5D.

Patient satisfaction was measured with Global Perceived Effect (7-point Likert scale).

At each follow-up visit employment status, medication use, stimulation settings and/or adverse events were noted.

Each follow up visit lasted about 30 min during which the patient was seen by the treating physician and the nurse practitioner.

Statistical Analysis

Descriptive statistics were used to summarize study data. They were reported as percentages or as mean ± standard deviation.

Student's *t*-test was used to compare for statistically significant differences. These tests were performed using Microsoft Office Excel (Redmond, WA, USA). The level of statistical significance (*p*-value) was set at 5%.

Separated pain scores for low back pain and leg pain, QBPDS, EQ-5D and Patient satisfaction after 12-month follow-up were compared with baseline.

RESULTS

Thirteen patients were included in the study and signed an Informed consent.

One patient chose an alternative therapy and discontinued the study.

Twelve patients received one or two SCS electrodes for trial stimulation. In one patient, coverage with paraesthesia was inadequate during intra operative stimulation. This patient also discontinued the study.

Eleven patients had more than 50% pain relief at the end of the trial period and were implanted with a neurostimulator. These patients were followed in the study.

During follow up between 6 and 12 months two other patients discontinued the study.

In one patient (no: 8) low back pain returned despite optimal stimulation settings. The second patient (no: 5) was neither satisfied with either LD or HD stimulation and had the system explanted.

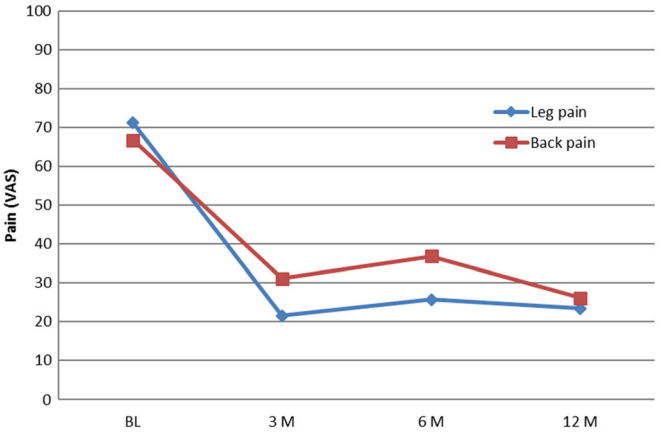

Figure 2. Pain scores (visual analog scale, VAS) for leg (blue) and back (red). BL, baseline; M, months follow-up. [Color figure can be viewed at wileyonlinelibrary.com]

Table 1 shows the results of the pain scores of the low back and leg pain at baseline and up to 12 months follow-up. The mean back pain score at baseline was 66.7 ± 33.2 and reduced to 36.8 ± 41.6 and 26.1 ± 33.2, respectively at 6 months at 12 months ($p < 0.01$).

Leg pain at baseline was 71.2 ± 33.8 and decreased to 25.7 ± 24.0 and 23.4 ± 32.0, respectively at 6 and 12 months ($p < 0.01$). The results of the pain scores over time are displayed in Figure 2.

The results of the Quebec Back Pain and Disability questionnaire are shown in Table 3. At baseline the score was 59.2 ± 12.2 and improved to 46.2 ± 18.3 and 44.1 ± 13.7, respectively, at 6 and 12 months ($p = 0.01$).

The quality of life total score (Table 4) improved from 0.24 ± 0.12 at baseline to 0.53 ± 0.32 and 0.68 ± 0.23, respectively, at 6 and 12 months ($p = 0.02$ at 6 M; $p < 0.01$ at 12 M). The generic health state improved 40 ± 12 at baseline to 60 ± 15 and 64 ± 18, respectively, at 6 and 12 months follow-up ($p < 0.01$ at 6 M; $p < 0.01$ at 12 M).

Figure 3 shows patients reported improvement over time. Overall patient reported slight improvement.

At the start of the study seven of eleven patients were unable to work because of their CBLP. Four patients were working part-time. One year after SCS-HD, three patients had returned to full time employment and two others had started part-time work.

Table 3. Quebec Back Pain Disability Scale.

Patient	Baseline	3 months	6 months	12 months
1	50	50	59	58
2	70	36	41	38
3	74	59	66	56
4	45	19	22	34
5	58	13	47	-*
6	41	11	13	15
8	76	68	-	-
9	50	36	41	48
10	71	62	68	52
11	54	38	44	42
12	62	43	61	54
Mean (SD)	59.2 (12.2)	39.5 (19.4)	46.2 (18.3)	44.1 (13.7)

* Explanted due to loss of effect.

Table 4. Quality of Life (EQ-5D).

	Baseline	3 months	6 months	12 months
Total score, mean (SD)	0.24 (0.12)	0.60 (0.26)	0.53 (0.32)	0.68 (0.23)
Health state, mean (SD)	40 (12)	69 (16)	60 (15)	64 (18)

Medication

Table 5 shows the pain medication use at baseline and up to 12 months follow up. One patient (no: 11) did not use any pain medication at the start and during follow up. Although reduction of pain medication was not an aim of the study, several patients decreased pain medication dosage or were able to use less powerful painkillers.

Stimulation

One patient preferred LD-SCS rather than HD-SCS (no: 11). All other patients used HD-SCS. During the follow-up period patients began using both stimulation forms and alternated LD-SCS and HD-SCS depending on their needs. After 12 months, six patients solely used HD-SCS, one patient preferred LD-SCS and two patients (no: 1 and 10) used both stimulation paradigms.

Figure 4 shows the anatomical placement of the leads and active electrodes (anodes and cathodes) at 12 months follow up based on paraesthesia coverage over the painful area.

Patient no 1, who had 50% low back pain area, we stimulated at the bottom of Th10, which is a very low position to normally find the low back pain area. However, during the intraoperative screening we searched from Th7 to Th12 and were successful at this low level. After 3, 6, and 12 months this patient, while using both LD- and HD-SCS, reported a pain score of VAS: 22, 24, 44 respectively for low back pain.

The time and frequency of recharging the IPG varied from 1 hour every 2 days to 2 hours per week.

Adverse Events

A total of six adverse events were reported in the follow-up period of 12 months. Two patients left the study between 6 and 12 months follow-up. In one patient (no: 8) low back pain returned nine months after initiation of SCS despite optimal stimulation settings. The second patient (no: 5) was neither satisfied with LD nor HD stimulation and had the system explanted.

One patient developed (no: 9) pain at the site of the IPG in the left upper part of the buttock shortly after implant, which was successfully treated with Qutenza patch.

One patient (no: 2) was involved in a car accident and consequently developed recharging problems because of a haematoma at the stimulator site. This problem was resolved within a few weeks without intervention.

Some patients made unscheduled visits to the outpatient clinic for different reasons. These were: emotional and other problems (eg, family members with progressive dementia, or severe depression, and participating patients' headaches, hip and vascular problems). These patients were treated with medication or were referred to another specialist. None of these problems required additional pain treatments or surgical interventions.

DISCUSSION

In this pilot study we investigated the effect of high-dose (HD) SCS as an additional programming option to (conventional) LD-SCS for treatment of CBLP in patients with FBSS. During trial SCS, patients were given both stimulation paradigms. They all started with LD-SCS and after three days changed to HD-SCS. Responders to SCS were given an option to use their preferred mode of stimulation. The short and long-term results showed good reduction of CBLP in these patients.

High Frequency/High Dose

The results of our study are comparable to other studies using higher frequency modes, such as HF10 and burst, in both patients newly receiving SCS (7–9,12,13,15–17) and patients who lost effect of SCS over time (6,9,14).

In our study we used a frequency of 420 Hz and a pulse width of 400 μsec, which is a duty-cycle of 16.8% (3). This is lower than the duty-cycle with 10-kHz High-Frequency (30%) or burst (25%) and in line with work by Wille et al. (6) (mean duty-cycle 13%). Note: the other above-mentioned studies do not provide information on the pulse duration used. When we include the stimulation amplitude in these high-density stimulation modes (ranging from 1 to 4 mA), the total charge per unit time that is delivered to the

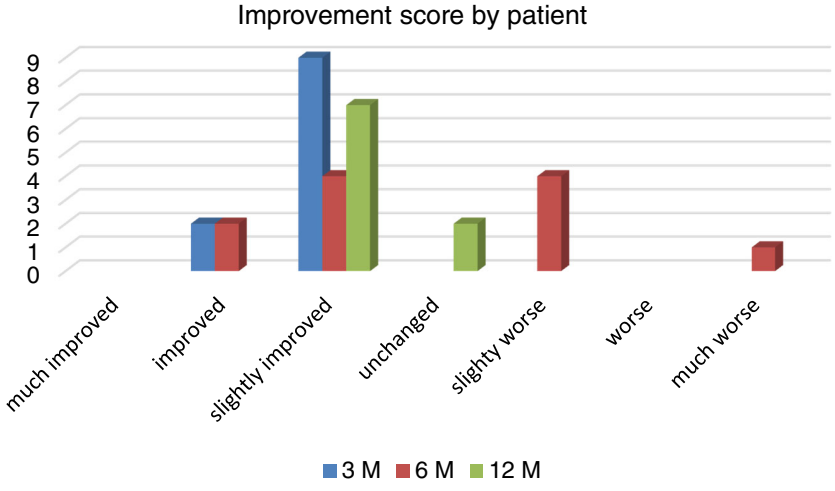

Figure 3. Patient rated improvement over time. [Color figure can be viewed at wileyonlinelibrary.com]

Table 5. Pain Medication Overview.

Patient	Baseline	3 months	6 months	12 months
1	pcm prn tramadol 3 × 100 mg	pcm prn tramadol 2-3 × 50 mg	pcm prn tramadol 1-2 × 50 mg	pcm prn tramadol 1-2 × 50 mg
2	pcm 2 × 500 mg prn diclofenac 50 mg prn tramdol prn lyrica (pregabaline)2 × 75 mg amitiptyline 1 × 20 mg	pcm zn 2 × 500 mg diclofenac prn 1 × 50 mg tramadol prn 1 × 50 mg lyrica 2 × 75 mg amitiptyline 1 × 20 mg	pcm prn 2 × 500 mg diclofenac prn 1 × 50 mg tramadol prn 1 × 50 mg lyrica 2 × 75 mg amitiptyline 1 × 20 mg	pcm prn 2 × 500 mg diclofenac prn 1 × 50 mg tramadol prn 1 × 50 mg lyrica 2 × 75 mg amitiptyline 1 × 20 mg
3	pcm 2 × 500 mg ibuprofen 600 mg prn fentanyl 12 mcg lyrica 2 × 75 mg	fentanyl 12 mcg	fentanyl 12 mcg pcm 2-4 × 500 mg ibuprofen 2-4 × 600 mg	fentanyl 12 mcg pcm 2-4 × 500 mg ibuprofen 2-4 × 600 mg
4	pcm 4 × 1 g. diclofenac 3 × 50 mg	pcm prn	pcm prn	pcm prn
5	lyrica 2 × 75 mg tramadol 2 × 50 mg	-	lyrica 2 × 225 mg	
6	amitiptyline 1 × 25 mg ibuprofen 5-6 × 600 mg pcm 5-6 × 500 mg diazepam prn	-	pcm 2 × 500 mg ibuprpfen 2 × 600 mg	pcm prn ibuprofen prn
8	tramadol 3 × 50 mg lyrica 3 × 150 mg celebrex 2 × 200 mg pcm 3-4 × 1 g	tramadol 3 × 50 mg celebrex 1 × 200 mg pcm 5-6 × 500 mg	tramadol 3 × 50 mg celebrex 1 × 200 mg pcm 5-6 × 500 mg	-
9	lyrica 2 × 75 mg amitriptyline 1 × 25 mg pcm 500 mg prn pcm/cod prn	lyrica 1 × 75 mg amitriptyline 1 × 25 mg oxycodon 10 mg wn	lyrica 1 × 75 mg amitriptyline 1 × 25 mg	lyrica 1 × 75 mg amitriptyline 1 × 25 mg
10	oxycontin 2 × 20 mg pcm 4 × 1 g	tramadol 1 × 50 mg pcm 4 × 1 g	zaldiar 2 xdd 1	zaldiar 2 xdd 1
11	-	pcm prn	pcm prn	pcm prn
12	oxycodon 2 × 15 mg + 1 × 10 mg lyrica 2150 mg amitriptyline 1 × 25 mg meloxicam 1 × 15 mg	-	lyrica 1 × 75 mg pcm 4-6 × 500 mg ibuprofen 1 × 400 mg	pcm prn pcm 4-6 × 500 mg ibuprofen 1 × 400 mg

pcm, paracetamol; prn, as needed.

neural tissue with HD-SCS is a factor of ten higher than used in conventional, low-dose stimulation. In most of these high-dose stimulation paradigms the stimulation amplitude is set to a level that prevents generation of paresthesias. It could be hypothesized that a minimal amount of charge is required to develop a clinically meaningful pain suppression. This is in accordance with the work of Wille et al. (6), who found a statistically significant difference in duty-cycle between HD-SCS responders (average 13.1%) and nonresponders (average 5.9%). Furthermore, optimizing the duty-cycle has significant implications for the battery usage and therefore the recharge frequency/time for rechargeable neurostimulators. Historically, 30 Hz stimulation was used with primary cell (nonrechargeable) internally powered generators to maximize battery life. Furthermore, the above is in line with de Ridder et al. (8) who argue that burst-SCS and 10-kHz high-frequency probably have the same mechanism of action.

Stimulation Amplitude

In our study the stimulation amplitude was set to a comfortable level by the patients. With conventional SCS all patients chose a level that gave paresthesia coverage over most of the painful area. With HD-SCS, using the same electrode configuration most patients set the amplitude to a level where they did not feel paresthesias. Although paresthesias were not experienced as problematic by the patients, most preferred HD-SCS at low amplitude levels. This is in line with findings from earlier studies, where stable stimulation amplitudes or subparesthesia stimulation were rated more comfortable (16).

SCS Paradigm Switching

In our study patients were offered both conventional and HD-SCS during the trial period. Conventional SCS is offered because over the years this stimulation paradigm has offered satisfactory outcomes for treatment of CBLP. Because some patients over time rate paraesthesias as bothersome, the use of HD-SCS may provide alternative paresthesia-free solutions. The patients who received the implanted neurostimulator were able to use both stimulation paradigms to their own liking. Over time we observed an increased use of HD-SCS to control their pain, whereas at 12 months follow-up all patients predominantly use HD-SCS. Nevertheless, some patients continue to switch between modes. This finding is in line with other work that describe the need for patients to change between kilohertz stimulation modes and conventional stimulation (18,19).

Anatomical Location of Active Electrodes

With the use of the HD-SCS paradigms (eg, 10 kHz, 1 kHz, and Burst) discussion has arisen on anatomical location of stimulation for treatment of CBLP. Because the working mechanism of HD-SCS is not yet defined, it is unclear what anatomical substrate this

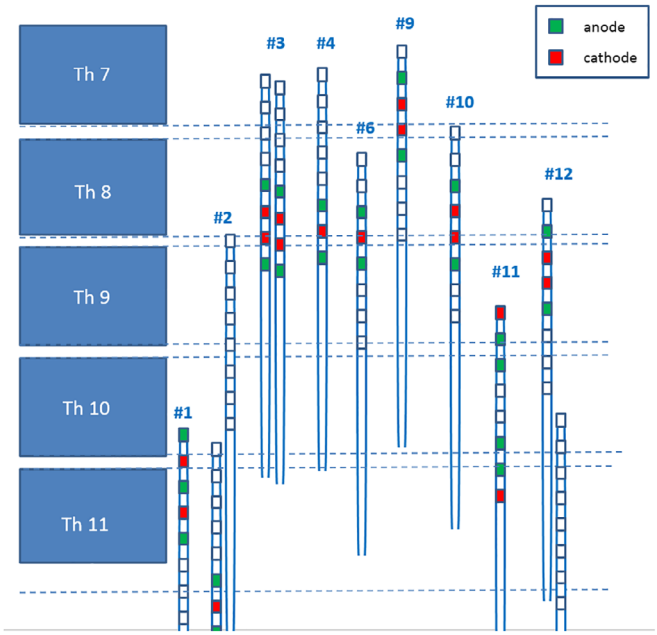

Figure 4. Lead positions and active electrodes (anodes and cathodes) for the individual patients. [Color figure can be viewed at wileyonlinelibrary.com]

stimulation paradigm acts upon. With 10-kHz High-Frequency the target is anatomical placement at T9 to T10 (bipolar stimulation), whereas with Burst-SCS and 1 kHz the guidance is based on paraesthesia coverage over the painful area.

Similarly, as for Burst and 1 kHz, in our study the location of the electrodes in the epidural space was determined by covering the whole pain area with paresthesias during the intraoperative procedure. In three patients two 8-polar electrodes were needed to cover the whole pain area, whereas in all other patients a single eight-polar electrode was sufficient. In five patients good CBLP pain relief was achieved with stimulation at level T8 to T9. Based on the findings in earlier work (6) and the observed large variability of the position of the active electrodes with HD-SCS in our study, we recommend to program HD-SCS on paraesthesia mapping guidance.

Rechargeable or Nonrechargeable Battery

Because of the higher energy delivery (estimated tenfold higher) with the HD-stimulation modes compared to LD-SCS, this has significant implications for the choice of the implantable neurostimulator. In most cases where HD-SCS is programmed a rechargeable battery is needed. A recent study from van Buyten et al. (20) in a large retrospective chart review study showed a higher explant rate for rechargeable batteries than nonrechargeable systems over 5 years. In that article the authors argue that the higher explant rate is often due to inadequate pain relief caused by patient compliance and/or physiological factors and technological aspects/issues. Possible solutions include: rapid charging, wireless communication, smaller batteries, ergonomic shapes with updateable software. Although SCS is a very effective therapy for patients with refractory CBLP, it is also expensive so careful selection of patients, discussed in a multidisciplinary setting, is very important. When a patient is a candidate for a rechargeable neurostimulator due to HD-SCS programming, he or she not only needs to be informed on how to use the system (charging), but also on the potential recharging recurrence. Currently systems with a larger battery capacity and rapid recharging are on the market thus helping with patient compliance to SCS.

Limitations of the Study

The limitation of this pilot study is a small patient sample and the lack of a comparative group in a controlled setting. As a result, it is not possible to draw conclusions from the results obtained from this group. This pilot study was intended to learn and evaluate the value of HD-SCS in addition to LD-SCS. We only changed the frequency and pulse width on the electrodes that were selected with paraesthesia mapping as guidance for SCS and cannot make any claims on anatomically guides electrode selection.

CONCLUSION

HD-SCS programming shows a promising long-term effect on low back pain and leg pain in patients with FBSS. The paresthesia guided placement of the SCS-leads gives the opportunity for HD-SCS as well as conventional, LD-SCS, depending on the individual's preference. The results obtained from this study may help the design of a randomized controlled trial in a larger group of patients.

Authorship Statements

This study was an initiative from all four authors. All were involved in the development of the protocol, the recruitment of patients and data analysis. Ismail Gültuna, Hans Aukes, and E. J. van Gorp performed surgery. Tanja E. Hamm-Faber assisted with surgery and collected data. Tanja E. Hamm-Faber prepared the manuscript with the intellectual input of Ismail Gültuna, Hans Aukes, and E. J. van Gorp. All authors had complete access to the study data and approved the final manuscript. Preliminary results were presented at the INS in Edinburgh 2017.

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COMMENT

Sub-perception programming is part of the future of SCS. It appears that there are many ways to achieve this. This paper emphasizes the use of a duty cycle (the time that the device is actually imparting current). However, some would say that this is not the final common pathway.

The authors also touch upon whether the sub-perception programming is targeted based upon paresthesia responses or if there is an anatomical target.

We are still in an era of discovery but at least a consensus is developing.

The other consensus that most practitioners now accept is that some patients prefer paresthesia based (in this paper "Low Density") and others prefer sub-perception or to toggle between the two. One waveform only is not the mantra we hear nowadays.

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Comments not included in the Early View version of this paper.

