ORIGINAL RESEARCH ARTICLE

Cost-Effectiveness of Spinal Cord Stimulation Therapy in Management of Chronic Pain

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Abstract

**Objective. To evaluate the cost-effectiveness of
spinal cord stimulation (SCS) and conventional
medical management (CMM) compared with CMM
alone for patients with failed back surgery syndrome
(FBSS), complex regional pain syndrome (CRPS),
peripheral arterial disease (PAD), and refractory
angina pectoris (RAP).**

**Design. Markov models were developed to evaluate
the cost-effectiveness of SCS vs CMM alone from**
the perspective of a Canadian provincial Ministry of
Health. Each model followed costs and outcomes in
6-month cycles. Health effects were expressed as
quality-adjusted life years (QALYs). Costs were
gathered from public sources and expressed in
2012 Canadian dollars (CAN$). Costs and effects
were calculated over a 20-year time horizon
and discounted at 3.5% annually, as suggested
by the National Institute of Clinical Excellence.
Cost-effectiveness was identified by determini-
stic and probabilistic sensitivity analysis (50,000
Monte-Carlo iterations). Outcome measures were:
cost, QALY, incremental net monetary benefit
(INMB), incremental cost-effectiveness ratio (ICER),
expected value of perfect information (EVPI), and
strategy selection frequency.

Results. The ICER for SCS was: CAN$ 9,293 (FBSS),
CAN$ 11,216 (CRPS), CAN$ 9,319 (PAD), CAN$ 9,984
(RAP) per QALY gained, respectively. SCS provided
the optimal economic path. The probability of SCS
being cost-effective compared with CMM was
75–95% depending on pathology. SCS generates a
positive INMB for treatment of pain syndromes.
Sensitivity analyses demonstrated that results were
robust to plausible variations in model costs and
effectiveness inputs. Per-patient EVPI was low,
indicating that gathering additional information for
model parameters would not significantly impact
results.

**Conclusion. SCS with CMM is cost-effective com-
pared with CMM alone in the management of FBSS,
CRPS, PAD, and RAP.**

**Key Words. Spinal Cord Stimulation; Chronic
Pain; Conventional Medical Management; Cost-
Effectiveness; Cost Comparison**

Introduction

Spinal cord stimulation (SCS) is a reversible and minimally
invasive neuromodulatory technique that has been suc-
cessfully applied for the treatment of various pain patholo-
gies including failed back surgery syndrome (FBSS) [1–4],
complex regional pain syndrome (CRPS) [5–7], refractory
angina pectoris (RAP) [8,9], peripheral arterial disease

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(PAD) [10,11], painful neuropathy, phantom limb, visceral pain, post-herpetic neuralgia, and low-axial back pain [4,12]. In these cases, conventional medical management (CMM) is less effective. Despite high up-front costs, evidence indicates that SCS is safe and effective. Therapeutic benefits are manifested in improved pain control, functional capability and health-related quality of life (HrQoL), and the potential for reduced utilization of health care resources [13–18]. Owing to device and operative costs, SCS is initially more expensive than CMM. With rising medical costs and limited health care budgets, it is important to evaluate both clinical and economic implications of new interventions.

Long-term cost-effectiveness data are limited. Economic analyses to date have been largely confined to FBSS and CRPS [13–17]. The aim of this study was to evaluate the long-term costs and effectiveness of SCS and CMM, collectively referred to as the SCS strategy, compared with CMM alone in patients with FBSS, CRPS, PAD, and RAP using Markov decision analytic models. We have performed deterministic and probabilistic sensitivity analyses in order to generate incremental cost-effectiveness ratios (ICERs), calculate incremental net monetary benefits (INMBs), plot cost-effectiveness acceptability curves (CEACs), determine expected value of perfect information (EVPI), and calculate strategy selection frequency.

A cost-utility analysis is a type of cost-effectiveness analysis that examines the costs and effectiveness of interventions by employing the quality-adjusted life year (QALY) as its measure of effectiveness. Cost-utility analyses examine the effects of interventions on both quantity and quality of life and are considered the standard for reporting of cost-effectiveness analyses and aid policy-makers in formulating decisions on health care resource distribution [19–24]. Quality of life is increasingly recognized as an important issue in the assessment of disease and treatment effects. The examination of cost per QALY is particularly relevant to chronic pain because of its marked impact on quality of life. Moreover, the QALY serves as a generic measure of health benefit that allows the cost-effectiveness of pain treatments to be compared with other treatments in non-pain therapy areas as well.

Methods

This study was conducted in accordance with the guidelines and reporting structures set forth by the Canadian Agency for Drugs and Technologies in Health [24]. The analysis takes the perspective of a Canadian provincial Ministry of Health, thus only direct medical costs are included. Outcomes and treatment costs were modeled over a 20-year time horizon, which is within the range of SCS observational data available at our center. Although chronic pain usually encompasses the duration of a patient's life expectancy, the lack of robust outcome data on SCS cohorts available to us beyond 20 years made us reluctant to pursue longer extrapolation time frames. Furthermore, rapid advances in technology beyond this time

frame may limit the clinical relevance of longer extrapolation periods.

Ethics approval for the present study was obtained from the Regina Qu'Appelle Health Region Research Ethics Board.

Data Source

Three hundred and thirteen patients underwent a trial implant. Two hundred and sixty-three patients achieved ≥50% pain relief on trial stimulation and were selected to undergo implantation of a permanent SCS system. Of these 263, 184 patients had FBSS, 42 CRPS, 28 PAD, and 9 RAP. Seventy-two patients, which included 50 patients who failed trial stimulation and 22 who refused an SCS trial, provided data for the CMM group (49 patients had FBSS, 11 CRPS, 10 PAD, and 2 RAP). Patient characteristics in both strategies were similar with respect to age, sex, and underlying pathology (Table 1).

Markov Model Structure and Description

In order to examine the cost-effectiveness of SCS with adjunctive CMM (SCS) vs CMM alone, Markov models were constructed using TreeAge Pro 2011 (TreeAge Software, Inc, Williamstown, MA, USA). The Markov model is identically structured for each of the four pathologies under discussion (Figure 1).

Markov models follow patients as they pass through a series of clearly defined and mutually exclusive health states throughout the course of their disease. We used the data collected from patient chart review to establish costs, probabilities, and utility inputs for the generation of each Markov model. For the cost and efficacy parameters, the extremes of ±1 standard deviation from the mean were selected as reasonable upper and lower limits (Table 2).

The main health states included: 1) optimal health state (≥50% pain relief from baseline); 2) suboptimal health state; and 3) death. In each cycle, a patient's movement between health states is determined by transition probabilities and each health state is assigned costs for resource use and outcome consequences. By running the model over a number of cycles, the long-term costs and outcomes can be calculated.

Patients in the SCS strategy first undergo a trial implant. If trial implantation fails, the patient receives CMM only. Conversely, if the trial succeeds, the patient receives a permanent SCS implant and enters the optimal health state unless disease progresses or until a treatment-limiting adverse event occurs, which is captured by transition to a suboptimal health state. At this point, patients on SCS could either continue with SCS or switch to CMM. Similarly, patients in the CMM strategy may attain an: 1) optimal health state; 2) suboptimal health state; or 3) death. At any point in the model, patients could die due to any-cause mortality.

Table 1 Patient characteristics with 95% confidence intervals (CIs) for four chronic pain pathologies

	FBSS		CRPS		PAD		RAP	
	SCS	CMM	SCS	CMM	SCS	CMM	SCS	CMM
Number of patients	184	49	42	11	28	10	9	2
Mean age	49	50	51	50	70	72	68	69
% male	64	61	52	56	83	78	78	72
% female	36	39	48	44	17	22	22	28
Baseline								
Mean VAS	8.2	8.2	8.1	8.2	8.8	8.7	8.8	8.4
95% CI	(6.61–9.80)	(6.54–9.90)	(6.50–9.71)	(6.41–9.95)	(7.50–9.94)	(7.40–9.98)	(7.70–9.90)	(7.40–9.20)
Mean EQ-5D	0.28	0.29	0.30	0.32	0.17	0.16	0.32	0.30
95% CI	(0.18–0.39)	(0.19–0.37)	(0.21–0.38)	(0.23–0.41)	(0.11–0.22)	(0.12–0.20)	(0.25–0.41)	(0.21–0.40)
6 months								
Mean VAS	4.5	6.7	4.1	6.9	5.3	8.4	4.9	8.5
95% CI	(3.32–5.58)	(5.61–7.86)	(3.50–5.08)	(5.80–8.13)	(3.90–6.75)	(7.12–9.38)	(3.81–6.00)	(7.30–9.55)
Mean EQ-5D	0.60	0.33	0.57	0.28	0.54	0.23	0.54	0.22
95% CI	(0.51–0.69)	(0.24–0.42)	(0.50–0.64)	(0.20–0.36)	(0.48–0.61)	(0.15–0.31)	(0.46–0.62)	(0.13–0.31)

CI = confidence interval; CMM = conventional medical management; CRPS = complex regional pain syndrome; EQ-5D = EuroQoL; FBSS = failed back surgery syndrome; PAD = peripheral arterial disease; RAP = refractory angina pectoris; SCS = spinal cord stimulation; VAS = visual analog scale.

Model Assumptions

The model was constructed with a total of 40 treatment cycles, with each cycle representing 6 months. The model uses 6-month cycles to match treatment patterns (i.e., patients have the possibility to change from one health state to another every 6 months). In this model, the overall, long-term SCS complication rate is 19% per annum which is derived from review of our patient data. The complication rate was calculated by the occurrence of any reported complication; this included both biological and device-related complications. Costs associated with complications were calculated by taking a weighted average of all complications. It is conservatively assumed that any complications incurred in the CMM strategy did not impact cost or quality of life.

Discounting

An annual discount rate of 3.5% was applied to both costs and health benefits occurring beyond the first year, as recommended by the National Institute of Clinical Excellence (NICE) and utilized in the literature on cost-effectiveness of SCS [14,17,25,26].

Willingness to Pay (WTP)

The societal WTP threshold reflects the hypothetical limits to resources that society is willing to allocate for the benefit achieved by a medical intervention. In Canada [27], where this study was conducted, and the United States [28], a widely accepted WTP threshold is $50,000 per QALY gained. Figures of £20,000–£30,000 per QALY are also recognized in the United Kingdom [29].

Outcome

Quality of life assessments for all possible health states were based on the generic EuroQoL (EQ-5D) questionnaire and were obtained at 6 months follow-up for both strategies. In randomized control trials (RCTs) of SCS [1–3], patients are allowed to crossover if they are not satisfied with the arm to which they were initially assigned to after 6 months' follow-up. Thus, a 6-month cycle facilitates comparison with the literature.

In health economics, a utility value is a number that represents a given quality of life or state of health. An individual with a medical condition can be assigned a utility value between 1 (perfect health) and 0 (death) depending on how substantially the disease affects quality of life. Effectiveness as expressed in EQ-5D represents a valid, widely recognized way to measure patient outcomes [30–32]. Health effects were expressed in terms of QALYs gained. The ICER was calculated as cost per QALY gained. The formula for ICER is:

$$(\text{Cost}_{SCS} - \text{Cost}_{CMM}) \div (\text{Effectiveness}_{SCS} - \text{Effectiveness}_{CMM}).$$
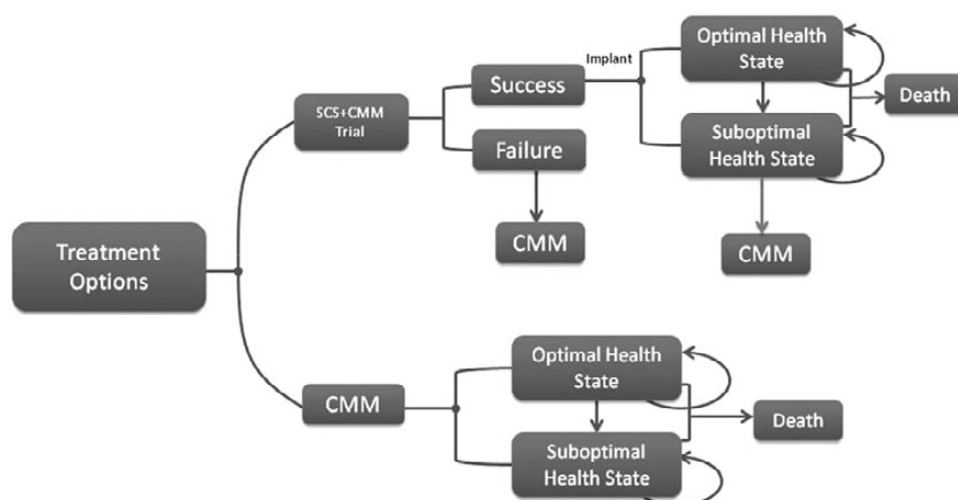
Figure 1 Markov model. The Markov model is identical in structure for each of the four pathologies; therefore, a representative diagram is presented. Time horizon = 20 years. Transition = arrows. Cycle length = 6 months. CMM = conventional medical management; SCS = spinal cord stimulation.

Sensitivity Analysis

Deterministic and probabilistic sensitivity analyses were conducted in order to identify key areas of uncertainty and determine model drivers. One-way deterministic sensitivity analyses were conducted for all major model variables. Findings were presented using a tornado diagram.

Results of probabilistic sensitivity analyses were presented using an ICER scatter plot graph based on 50,000 Monte-Carlo simulations. Each point in the resulting scatter plot represents the ICER of a single iteration of the Monte-Carlo simulation.

Net Monetary Benefit (NMB)

The NMB is defined as: (QALY gained × WTP) – Cost [33–36]. A positive NMB implies that the value of the additional benefit achieved exceeds the cost of therapy. Conversely, a negative NMB implies that an intervention should be rejected as its costs are higher than the value of the benefit achieved.

Cost-Effectiveness Acceptability Curve (CEAC)

The CEAC represents the probability that an intervention is cost-effective compared with an alternative, given a varying threshold for the WTP for each QALY gained. The CEAC was generated to evaluate the proportion of simulations where SCS can be considered cost-effective over a range of societal maximum WTP values for a QALY gained [35].

Expected Value of Perfect Information (EVPI)

Value of information analysis informs decision makers about the expected value of conducting more research in order to support a decision. In order to assess the consequences of a wrong decision per patient, EVPI was calculated, which combines both the probability of making a wrong decision and the consequences of that wrong decision expressed in terms of NMB forgone. The EVPI represents the value of parameter uncertainty that could be resolved by acquiring additional research evidence for model parameters. It provides an estimation of the maximum amount one should pay for additional information before taking the actual decision [33–35].

Strategy Selection Frequency

Another way to inspect the stability of a strategy is by means of the strategy selection frequency calculation. With a strategy selection frequency diagram, one gains information on how many times a strategy is selected over the possible combinations of the Markov model input values. Thus, if a strategy is more frequently selected, it is optimal. The strategy selection frequency is thus a measure of robustness which shows the percentage of the simulations in which the optimal treatment choice actually maximized QALYs [36,37].

Rechargeable vs Non-Rechargeable Implantable Pulse Generator (IPG)

In the literature, the life span of the non-rechargeable IPG is variable between 3–4 years [17] and 9 years for rechargeable IPGs [38]. We analyzed the

Table 2 Markov model input parameters

Variable*	FBSS		CRPS		PAD		RAP	
	Base case	Std dev	Base case	Std dev	Base case	Std dev	Base case	Std dev
Cost								
SCS								
Pre-implant (source: Hospital Finance Department)	$4,120	$515	$4,161	$495	$4,165	$529	$4,249	$546
Implant procedure (source: Hospital Finance Department)	$22,750	$2,844	$23,226	$2,764	$23,834	$3,027	$21,981	$2,825
Complications (source: Neuromodulation Clinic)	$467	$58	$425	$51	$481	$61	$443	$57
Maintenance (source: Neuromodulation Clinic)	$3,170	$396	$3,696	$440	$4,236	$538	$3,783	$486
Adjunctive therapy (source: Neuromodulation Clinic)	$1,130	$141	$1,141	$136	$1,142	$145	$1,165	$150
Pharmacotherapy (source: Neuromodulation Clinic)	$267	$33	$269	$32	$269	$34	$275	$35
CMM								
Evaluations and follow-up by health care providers (source: Patient Database)	$785	$98	$793	$94	$794	$101	$810	$104
Imaging (source: Patient Database)	$1,450	$181	$1,465	$174	$1,466	$186	$1,495	$192
Pharmacotherapy (source: Neuromodulation Clinic)	$800	$100	$808	$96	$809	$103	$825	$106
Alternative therapy (source: Patient Database)	$2,355	$294	$2,379	$283	$2,381	$302	$2,429	$312
Intermittent hospitalization/emergency room visits (source: Patient Database)	$1,500	$188	$1,515	$180	$1,517	$193	$1,547	$199
EQ-5D (source: Patient Database)								
Optimal CMM health state	0.54	0.07	0.52	0.06	0.51	0.06	0.54	0.07
Optimal SCS health state	0.62	0.08	0.59	0.07	0.55	0.07	0.56	0.07
Suboptimal CMM health state	0.32	0.04	0.27	0.03	0.22	0.03	0.21	0.03
Suboptimal SCS health state	0.41	0.05	0.42	0.05	0.37	0.05	0.32	0.04
Probability (source: Patient Database)								
Trial success	0.84	0.10	0.88	0.10	0.80	0.10	0.91	0.11
Optimal CMM health state	0.20	0.03	0.20	0.02	0.18	0.02	0.22	0.03
Optimal SCS health state	0.60	0.08	0.65	0.08	0.60	0.08	0.85	0.11
Transitioning from SCS suboptimal health state to an optimal health state in the CMM strategy	0.20	0.03	0.22	0.03	0.17	0.02	0.16	0.02
Suboptimal CMM health state	0.70	0.09	0.66	0.08	0.72	0.09	0.63	0.08
Suboptimal SCS health state	0.30	0.04	0.28	0.03	0.36	0.05	0.31	0.04
Transitioning from SCS suboptimal health state to a suboptimal health state in the CMM strategy	0.70	0.09	0.69	0.08	0.71	0.09	0.75	0.10
Death	0.008	0.00	0.008	0.00	0.05	0.01	0.05	0.01

* Cycle length = 6 months.
Cost, utility, and probability distribution.
Std Dev = standard deviation.
CMM = conventional medical management; CRPS = complex regional pain syndrome; FBSS = failed back surgery syndrome; PAD = peripheral arterial disease; RAP = refractory angina pectoris; SCS = spinal cord stimulation.

cost-effectiveness of rechargeable (RestoreAdvanced™, Medtronic of Canada, Ltd, Brampton, ON, USA) and non-rechargeable (PrimeAdvanced™) IPGs by plotting the NMBs generated by using each type of pulse generator as the life span of the non-rechargeable IPG was varied. For the purposes of analysis, rechargeable and non-rechargeable IPGs were considered equally efficacious.

Quantification of Costs

The cost basis for the SCS and CMM strategies was calculated by tabulating costs of the initial evaluation, physician visits, diagnostic procedures, adjunctive therapies, medications, and hospital stays for the treatment of breakthrough pain. In addition to this common base cost, the SCS group incurred additional expenses for costs of hardware, hospital and surgical fees for implantation, treatment costs of complications, ongoing follow-up, and pharmacotherapy.

At the time of writing, all actual costs are based on the Canadian dollar, which is trading almost at par with the US dollar. As this study was conducted in Regina, Saskatchewan, Canada, all cost references are taken from that province's fee schedule. The costs of the implantable devices were obtained from the manufacturer's price list (Medtronic of Canada, Ltd). Markup of these products is not permissible under Canadian law. Cost data were organized into the following categories:

Spinal Cord Stimulation (SCS) Group

1. *Pre-implant costs*: costs of evaluations/consultations by various health care professionals including family physicians, orthopedic surgeons, psychiatrists, social workers, neurologists, and neurosurgeons, and diagnostic procedures such as magnetic resonance imaging (MRI), computed tomography (CT) scanning, ultrasound and lumbar spine X-ray films;
2. *Implant procedure costs*: includes professional surgical and anesthesia fees, operating room fees, hospital stay, and equipment costs. Cost calculations are based on implantation of 2×8 octad percutaneous leads with a RestoreAdvanced™ rechargeable pulse generator (Medtronic of Canada, Ltd);
3. *Maintenance costs*: consisting of nursing contact, physician consultations, medication, costs for treating complications, hospitalizations for acute exacerbation of pain;
4. *Adjunctive therapy costs*: such as acupuncture, physiotherapy, massage, and chiropractic therapy;
5. *Pharmacotherapy costs*: includes drug and dispensing costs.

Conventional Medical Management (CMM) Group

Costs for this group include:

1. *Costs of evaluations by various health care professionals*: including family physicians, orthopedic surgeons, psychiatrists, social workers, neurologists, and neurosurgeons;

2. *Imaging costs (CT, MRI, X-ray, and ultrasound studies)*: required initially and during episodes of pain flare-up;
3. *Costs of alternative therapies*: such as epidural steroid blocks, trigger point injections, nerve blocks, physiotherapy, chiropractic treatments, massage therapy, and acupuncture;
4. *Pharmacotherapy costs*: includes drug and dispensing costs.
5. *Costs of intermittent hospitalization*: for treatment of acute breakthrough pain.

Personnel Costs

Health care professional fees are determined through negotiations between various professional groups and the provincial health department. Professional fees calculated in this study are based on the year 2012 payments. The costs associated with nursing contacts were calculated according to the hourly wage earned by the neuromodulation nurse. Similarly, costs calculated for contact with physiotherapists, chiropractors, massage therapists, and acupuncturists reflect actual therapy costs.

Diagnostic Costs

The frequency of the imaging procedures performed was extracted from all patients' charts. The cost of each imaging procedure was derived from the actual costs incurred by the hospital as determined by the finance department of the Regina Qu'Appelle Health Region.

Hospitalization Costs

Hospitalization costs at the Regina General Hospital, where the study was based, are $1,500 per patient per day.

Pharmacotherapy Costs

The commonly used drugs prior to and following implantation were opioid, antidepressant, non-steroidal anti-inflammatory, analgesic, or muscle relaxant agents. Costs of oral pharmacotherapy for each patient were calculated according to the Saskatchewan Health Formulary, allowing a predetermined government-approved pharmacist markup schedule and a flat rate for dispensing according to pharmaceutical standards.

Results

Costs at 6 Months

A cost comparison breakdown for SCS and CMM in the management of FBSS in the first 6 months of treatment is presented in Figure 2.

Incremental Cost-Effectiveness Ratio (ICER)

Projected 20-year costs, QALYs gained, and resultant ICERs are listed in Table 3. The ICER of SCS vs CMM alone was:
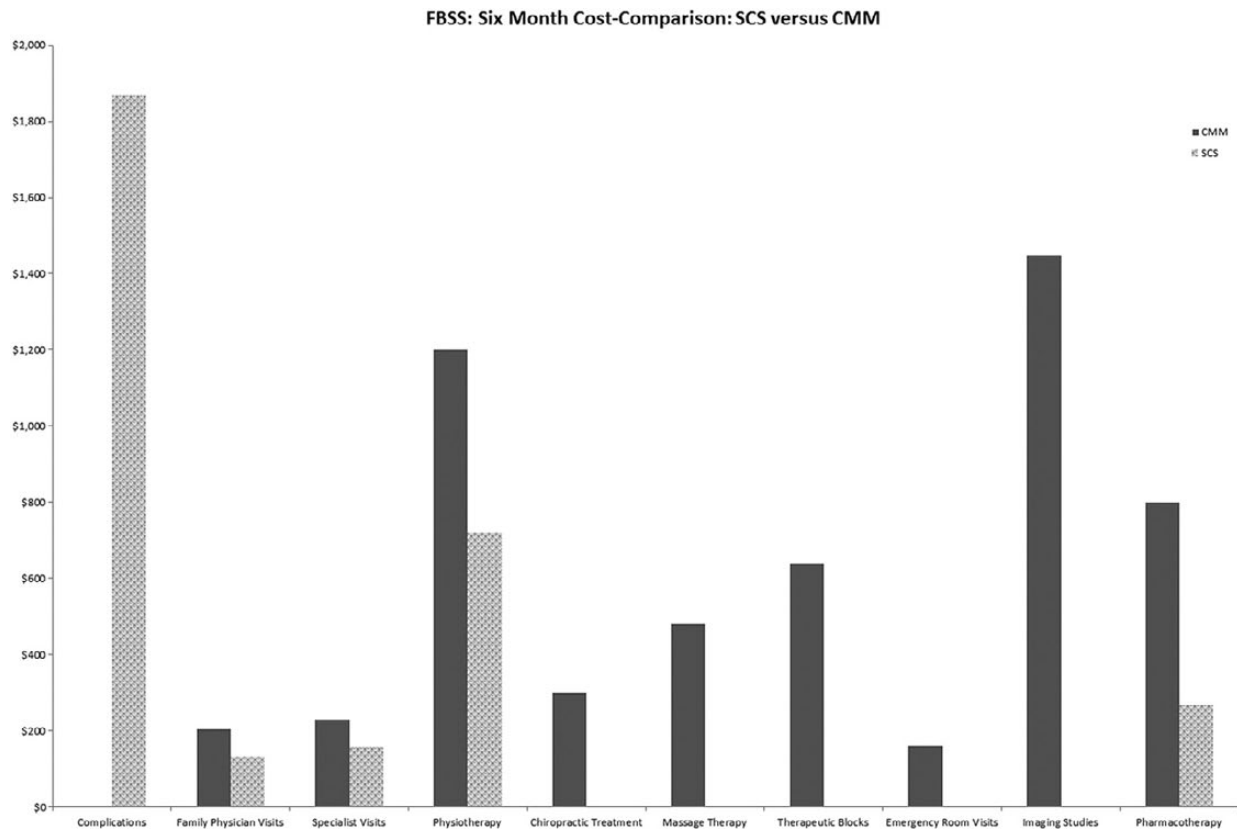
FBSS: Six Month Cost-Comparison: SCS versus CMM

Figure 2 Costs of 6 months of therapy for spinal cord stimulation (SCS) and conventional medical management (CMM) in a typical failed back surgery syndrome (FBSS) case.

A) FBSS: CAN$ 9,293 per QALY gained.
B) CRPS: CAN$ 11,216 per QALY gained.
C) PAD: CAN$ 9,319 per QALY gained.
D) RAP: CAN$ 9,984 per QALY gained.

Sensitivity Analysis

Due to space constraints, we have diagrammatically presented the results of deterministic and probabilistic sensitivity analyses for only FBSS in Figure 3. The trends for the other pathologies were similar.

Deterministic Sensitivity Analysis

The tornado diagram ranks parameters in order of their comparative influence and indicates the variables the base case SCS strategy is most sensitive to.

A) FBSS: 1) probability of securing an optimal health state with SCS; 2) probability of obtaining a suboptimal health state with SCS; and 3) the probability of achieving a suboptimal health state with CMM after failure of SCS trial. Figure 3a.
B) CRPS: 1) probability of securing an optimal health state with SCS; 2) probability of obtaining a suboptimal

health state with SCS; and 3) the probability of achieving a suboptimal health state with CMM after failed SCS trial.
C) PAD: 1) QALYs gained in the optimal health state with SCS; 2) probability of obtaining an optimal health state with SCS; and 3) QALYs gained in the SCS suboptimal health state.
D) RAP: 1) cost of the optimal health state with SCS; 2) cost of the suboptimal health state in the CMM strategy; and 3) probability of achieving an optimal health state in the SCS strategy.

Probabilistic Sensitivity Analysis

For cost per QALY gained, the grouping on the probabilistic cost-effectiveness plane represents a tight cluster and thereby provides analytical validity for the base case results. Figure 3b illustrates the cost-effectiveness plane for FBSS.

Incremental Net Monetary Benefit (INMB)

In each decision analytic model when SCS was compared with CMM alone, SCS provided a positive INMB at a WTP ≥$7,000 per QALY gained. INMBs are illustrated in Figure 4 and enumerated in Table 4.

Table 3 Incremental cost-effectiveness ratio (ICER) of spinal cord stimulation (SCS) per patient; time horizon = 20 years

Strategy	SCS+CMM	CMM
FBSS		
Cost (CAN$)	$166,439	$153,522
Effectiveness (QALY)	4.84	3.45
ICER (cost per QALY gained)*	$9,293	
CRPS		
Cost (CAN$)	$172,577	$148,799
Effectiveness (QALY)	4.24	2.12
ICER (cost per QALY gained)*	$11,216	
PAD		
Cost (CAN$)	$178,288	$162,725
Effectiveness (QALY)	4.32	2.65
ICER (cost per QALY gained)*	$9,319	
RAP		
Cost (CAN$)	$182,366	$160,302
Effectiveness (QALY)	4.88	2.67
ICER (cost per QALY gained)*	$9,984	

* Per patient.
CMM = conventional medical management; CRPS = complex regional pain syndrome; FBSS = failed back surgery syndrome; PAD = peripheral arterial disease; QALY = quality-adjusted life year; RAP = refractory angina pectoris.

Acceptability of Treatment

CEACs are displayed in Figure 5. At a WTP of $50,000 per QALY, the probability of SCS strategy providing a cost-effective alternative to CMM alone was:

FBSS: 75%; CRPS: 87%; PAD: 93%; RAP: 95%.

Expected Value of Perfect Information (EVPI)

The per-patient EVPI is relatively low compared with overall treatment costs for SCS, indicating that additional parameter sampling would not significantly alter results (Figure 6).

Strategy Selection Frequency

The strategy selection frequency diagram (Figure 7) shows the percentage of iterations that favor each strategy at a WTP threshold of CAN$ 50,000. As is evident in Figure 7, the SCS strategy provided the optimal economic path, when compared with CMM, in the majority of simulations for all pathologies.

Rechargeable vs Non-Rechargeable IPG

In a separate analysis, we examined the cost-effectiveness of rechargeable and non-rechargeable IPGs by calculating NMB generated. The results indicate that when the longevity of a non-rechargeable IPG is less than 4.25 years, a rechargeable (initially more expensive) IPG is more cost-effective (Figure 8).

Discussion

Despite increases in average unit costs for implantation and follow-up, this study shows that SCS remains cost-effective. The past 40 years has witnessed an expansion in the application of SCS therapy. In spite of accomplishments on the therapeutic side, barriers to reimbursement persist.

An intervention is considered cost-effective if its ICER falls below societal WTP per QALY thresholds. Figures of $50,000 (United States [28] and Canada [27]) and £20,000–£30,000 per QALY (United Kingdom [29]) are often cited as credible thresholds. In this article, the ICER for SCS fell well below these commonly accepted WTP thresholds. The EVPI estimate per patient was relatively low compared with total per-patient costs, indicating that gathering additional information for model parameters is unlikely to have a significant impact on results.

In all four pathologies, SCS provided a positive INMB over CMM at WTP thresholds ≥$7,000 per QALY. The probability of SCS providing a cost-effective alternative to CMM ranged from 75–95%, depending on pathology and WTP. The sensitivity analyses indicated that results were robust to plausible variations in model inputs. Taken together, these results suggest that SCS therapy represents a cost-effective use of resources.

Superficially, it may appear that by examining pain relief achieved by SCS and improvement in HrQoL, all aspects of the health state of individuals with RAP or PAD may be not fully captured. However, in these two pathologies, pain is the predominant symptom that brings patients to the attention of pain management physicians. It has been shown that the relief of pain is reflective of the improvement in quality of life and various clinical indices such as the Canadian Cardiovascular Society grading system score and specific measures such as the Seattle Angina Questionnaire [39,40]. It is known that PAD and RAP are associated with increased mortality, which has also been taken into account by the higher mortality rates assigned in these models (Table 2). We had scaled the models to various time horizons including 5, 10, and 30 years and found the ICER and INMBs to be robust. The ICERs for PAD and RAP did not change appreciably at various time horizons. Taking these factors into consideration, the model structure is equally applicable to these two ischemic conditions.

Unfortunately, only a limited number of studies on the cost-effectiveness studies of SCS have been published. These studies tend to originate from centers in Canada and Europe. Therefore, we are restricted in making comparative evaluations with these countries (Table 5). Presently, there is a lack of literature on this subject from American centers. This study should provide an impetus to publish US data, which will likely support our results.
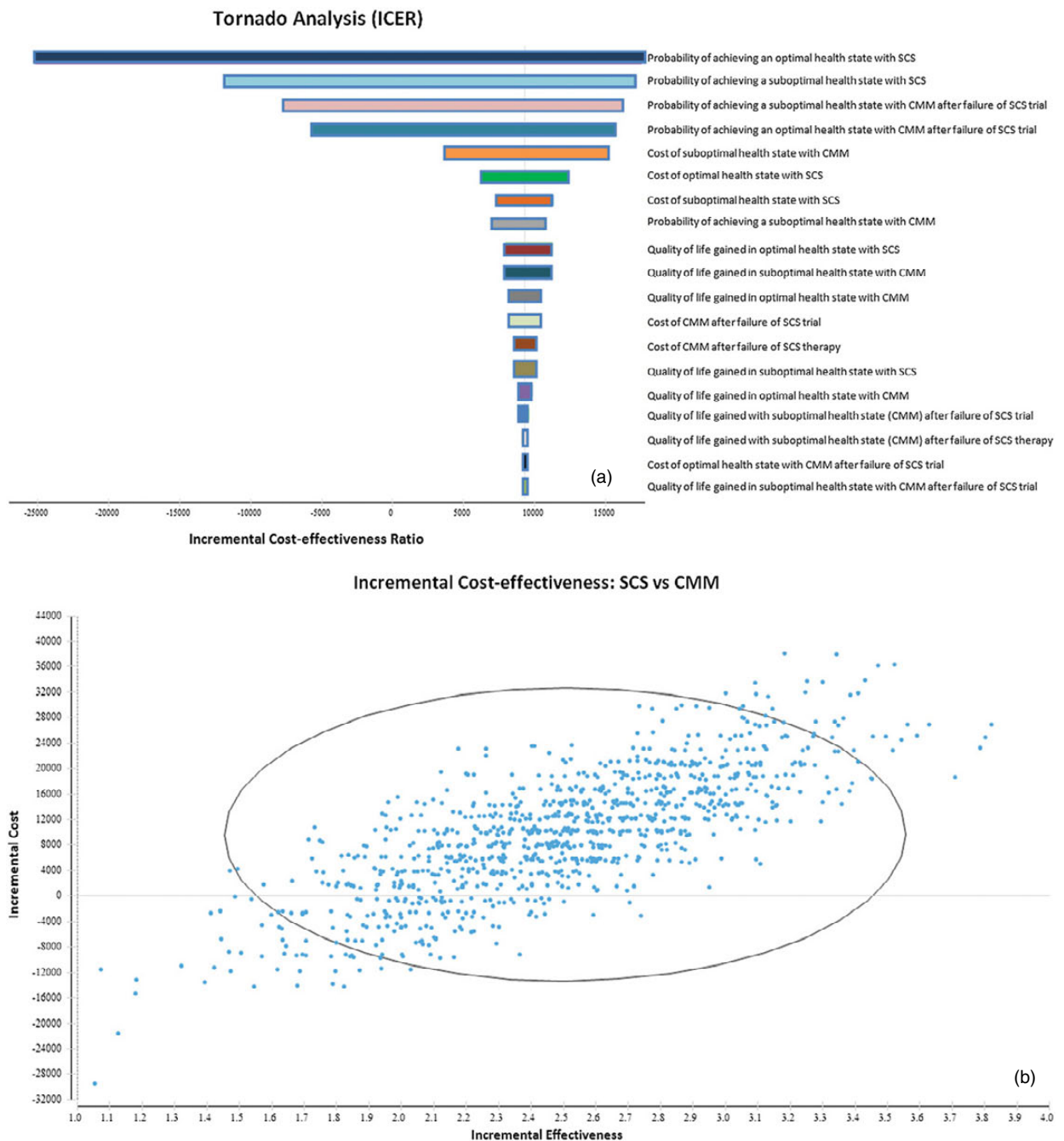
Figure 3 (a): Failed back surgery syndrome (FBSS). Tornado chart illustrating results from deterministic sensitivity analysis for incremental cost-effectiveness expressed as incremental cost per quality-adjusted life year (QALY) gained (CAN$). (b) FBSS. Probabilistic analysis spinal cord stimulation (SCS) vs conventional medical management (CMM)—results on the cost-effectiveness plane. *X*-axis represents incremental effectiveness (QALY). *Y*-axis represents incremental cost (CAN$). The majorities of simulations are tightly clustered, thereby providing analytical validity and robustness of projections. Time horizon = 20 years.
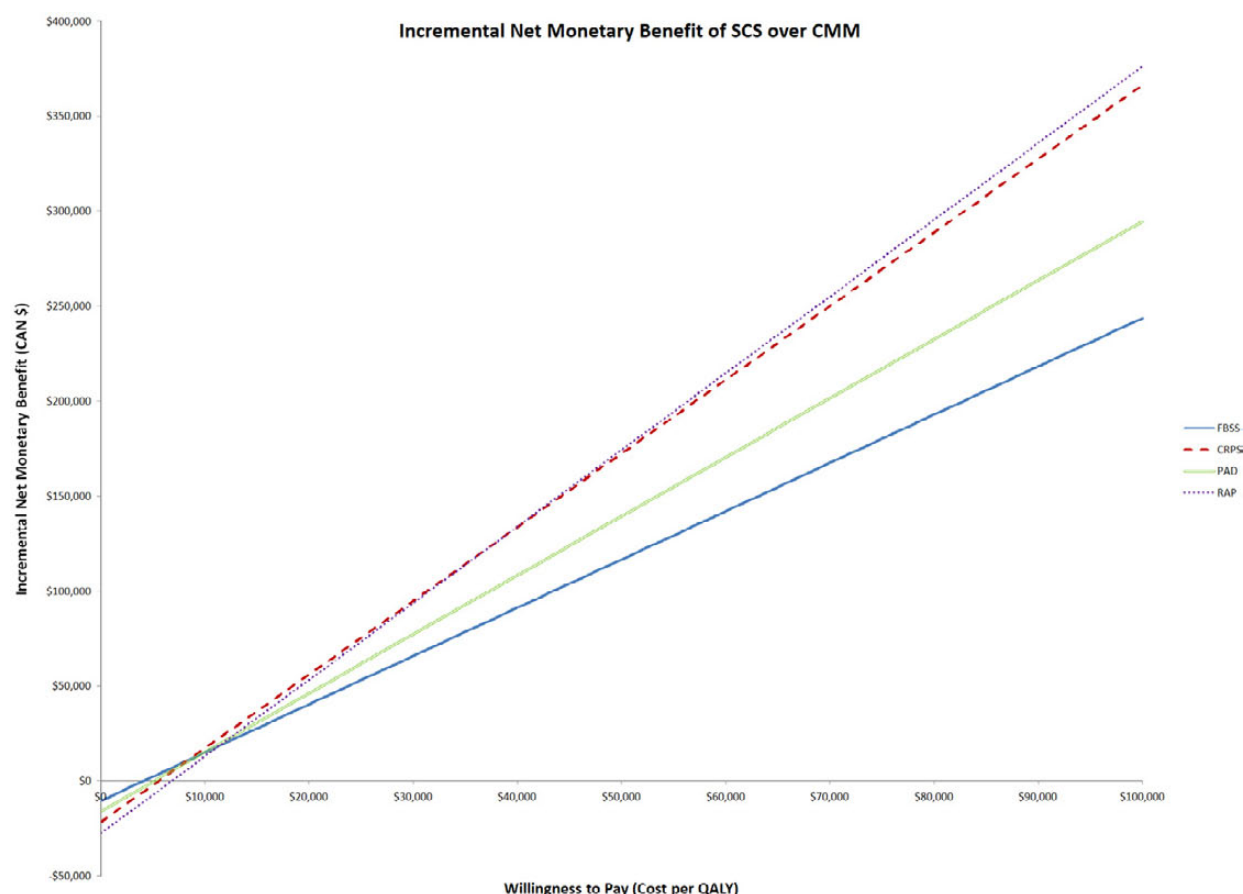
Figure 4 Incremental net monetary benefit for spinal cord stimulation (SCS) over conventional medical management (CMM) strategy at varying willingness-to-pay (WTP) thresholds. Instituting the SCS strategy over CMM generates a positive incremental net monetary benefit at WTP thresholds ≥$7,000 per quality-adjusted life year (QALY) gained. FBSS = failed back surgery syndrome; CRPS = complex regional pain syndrome; PAD = peripheral arterial disease; RAP = refractory angina pectoris.

FBSS

A comparison with literature is presented in Table 5. The overall trend points toward SCS as being highly cost-effective compared with CMM alone. The major differences pertain to time horizon (20 years for ours vs 15 years for Taylor et al. [17] and NICE evaluations [25]) and device selection (two octapolar leads and rechargeable IPG in this study vs quadripolar lead and non-rechargeable IPG in the comparative studies).

Our ICER is lower than NICE's [25] which is due to their assessment of CMM costs as being significantly lower and its effectiveness judged as being higher than observed in the present study. As part of the present analysis, we had access to the individual patient data and were thus able to directly estimate the proportion of patients who achieved 50% of more pain relief. In NICE's Association of British Healthcare Industries model, the difference in QALYs between SCS+CMM vs CMM alone was +1.25, which is

Table 4 Incremental net monetary benefits (INMBs) generated by the spinal cord stimulation (SCS) strategy (per patient); time horizon = 20 years

INMB of SCS vs CMM	WTP threshold of $50,000/QALY (Canada, United States)	WTP threshold of £20,000/QALY (United Kingdom)
FBSS	CAN$116,057	£44,772 (CAN$ 71,057)
CRPS	CAN$172,592	£64,772 (CAN$ 102,798)
PAD	CAN$139,549	£52,712 (CAN$ 83,659)
RAP	CAN$174,638	£64,206 (CAN$ 101,899)

CMM = conventional medical management; CRPS = complex regional pain syndrome; FBSS = failed back surgery syndrome; PAD = peripheral arterial disease; QALY = quality-adjusted life year; RAP = refractory angina pectoris; WTP = willingness to pay.
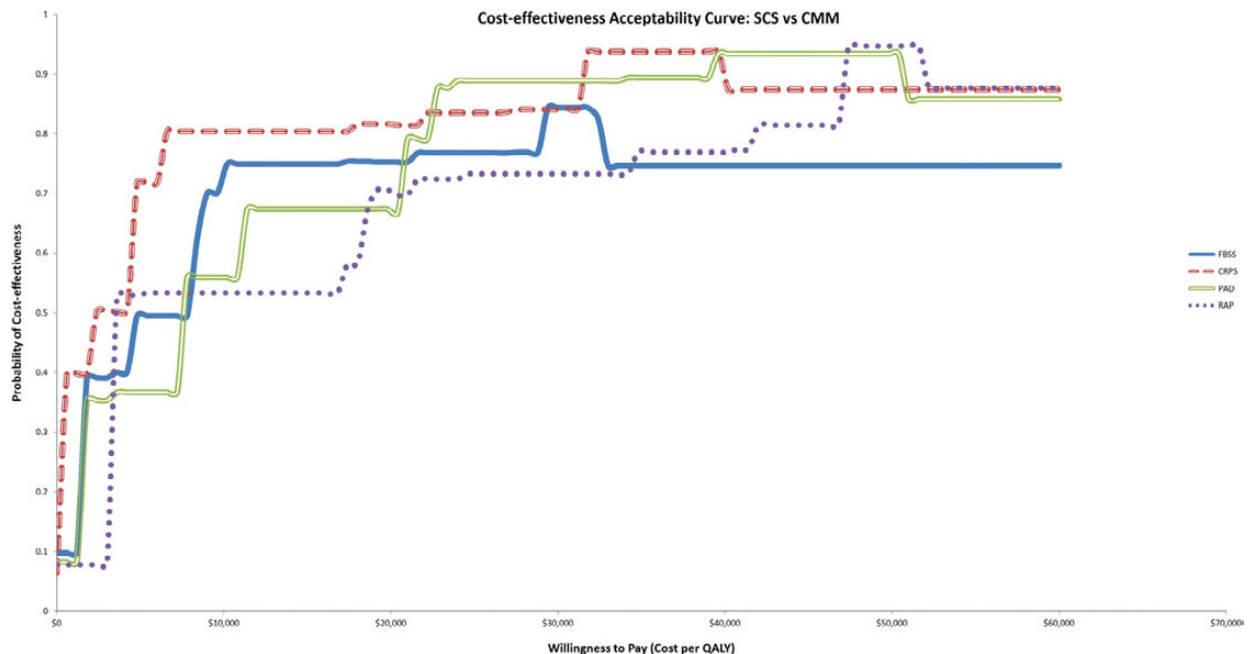
Figure 5 Cost-effectiveness acceptability curve. The probability of spinal cord stimulation (SCS) providing a cost-effective alternative to conventional medical management (CMM) ranged from 75–95% (dependent on pathology and willingness-to-pay threshold). QALY = quality-adjusted life year; FBSS = failed back surgery syndrome; CRPS = complex regional pain syndrome; PAD = peripheral arterial disease; RAP = refractory angina pectoris.

lower than the +1.39 QALYs gained by the SCS+CMM strategy in our model and pertain to model input parameters. The cost difference between the two strategies was also higher in the NICE model (£11,439) vs ours ($12,917). These factors account for the lower ICER encountered in our analysis.

Despite the use of newer generation leads and rechargeable IPG, our ICER remained similar to that reported by Taylor et al. [17]; this is likely a reflection of increased CMM costs, effect of time horizon, and improved quality of life with newer equipment.

CRPS

At present, no curative treatment for CRPS exists. CRPS responds poorly to conventional pharmacotherapy and other modalities such as transcutaneous electrical nerve stimulation, chemical blocks, chemical or surgical sympathetectomies, and physical and occupational therapy [41,42]. In contrast, SCS has been shown to reduce pain and allodynia and to improve limb function in patients experiencing CRPS [4–7].

Early institution of SCS may prevent development of dystrophic changes [6]. A comparison with published studies is presented in Table 5. Kemler and Furnee [13] calculated

a lower ICER than that reported in this study. The variation in results may be due to choice of model inputs, time horizon (20 vs 15 years), and hardware costs. For instance, the probability of a successfully screened patient achieving an optimal health state following SCS was 0.79 in the Kemler model vs a long-term success rate of 0.65 in the present analysis. The annual probability of complication reported by Kemler et al. [14] with SCS was also lower (12.5%) vs 19% in our model. Furthermore, the proportion of patients achieving an optimal health state with CMM was 5.6%, vs 20% in our model and 44% in the NICE assessment [25]; this may be related to our willingness to treat patients aggressively in the early stages of CRPS.

PAD

Our results indicate that SCS is worth implementing for the management of non-reconstructible PAD. Klomp et al. concluded that SCS was not cost-effective for management of critical limb ischemia [43,44]. However, quality of life was not assessed and the study time frame spanned only 2 years, making a comparison with our study difficult [44]. In their review, Ubbink et al. concluded that there is evidence to favor SCS over standard conservative treatment alone to improve limb salvage in patients with non-reconstructible critical limb ischemia [45].
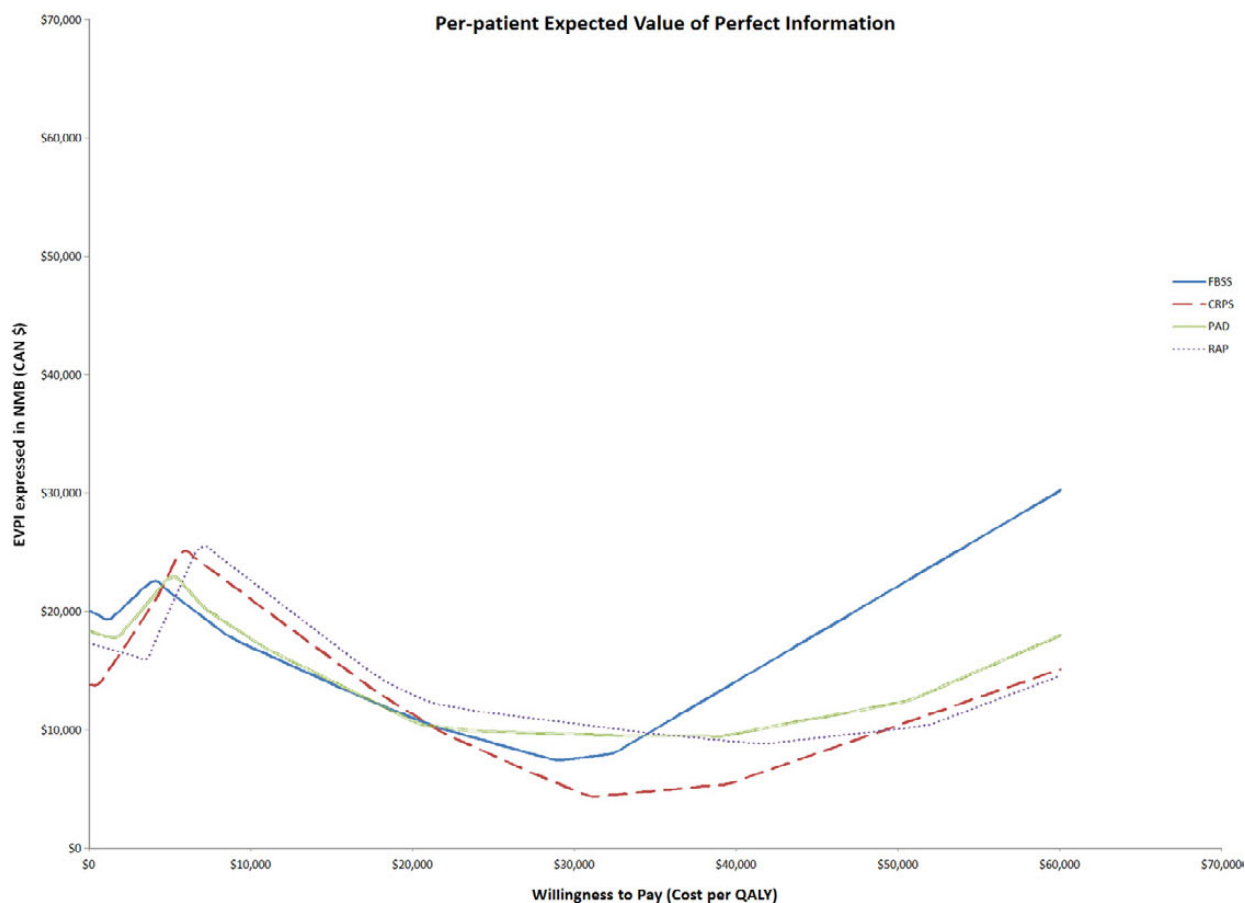
Figure 6 Expected value of perfect information (EVPI) for the spinal cord stimulation strategy. The EVPI estimate per patient was relatively low compared with the total per-patient costs, indicating that model inputs are robust and that gathering additional information for model parameters is unlikely to significantly affect the results of this study. QALY = quality-adjusted life year; FBSS = failed back surgery syndrome; CRPS = complex regional pain syndrome; PAD = peripheral arterial disease; RAP = refractory angina pectoris.

RAP

This article is the first to document the cost-effectiveness of SCS vs CMM for RAP-persisting post-coronary artery bypass grafting (CABG). An analysis of the electrical stimulation vs coronary artery bypass surgery in severe angina pectoris (ESBY) RCT [18] revealed that SCS and CABG were both cost-effective, with SCS having a lower initial cost, shorter duration of hospitalization, but higher overall hardware complication rate.

A cost-effectiveness analysis of the SCS vs percutaneous myocardial laser revascularization (PMR) in patients with RAP (SPiRiT) RCT failed to establish a favorable cost-effectiveness profile for SCS at 24 months follow-up [46,47]. Interestingly, significant changes in ICER were observed over time, which the authors attribute to a learning curve effect. For patients recruited during 2000/01, the

ICER of SCS over PMR was estimated at £230,000 per QALY, whereas for 2002/03, the ICER dropped to £18,000 per QALY. The investigators state that the improvement can largely be explained by better outcomes, in terms of survival and quality of life, experienced by SCS patients in the second half of the study. A direct comparison with the SPiRiT trial is not possible given that SCS was not directly compared with CMM in that study. It is also unclear whether CMM was available as an adjunct to one or both groups.

NICE analyzed the cost-effectiveness of SCS vs CABG [25]. The higher utility value in this study likely represents differences in the source population. For instance, in the NICE analysis, patients were eligible to receive CABG or SCS. In our analysis, however, patients were post-CABG and were still presenting with persistent, intractable anginal pain.
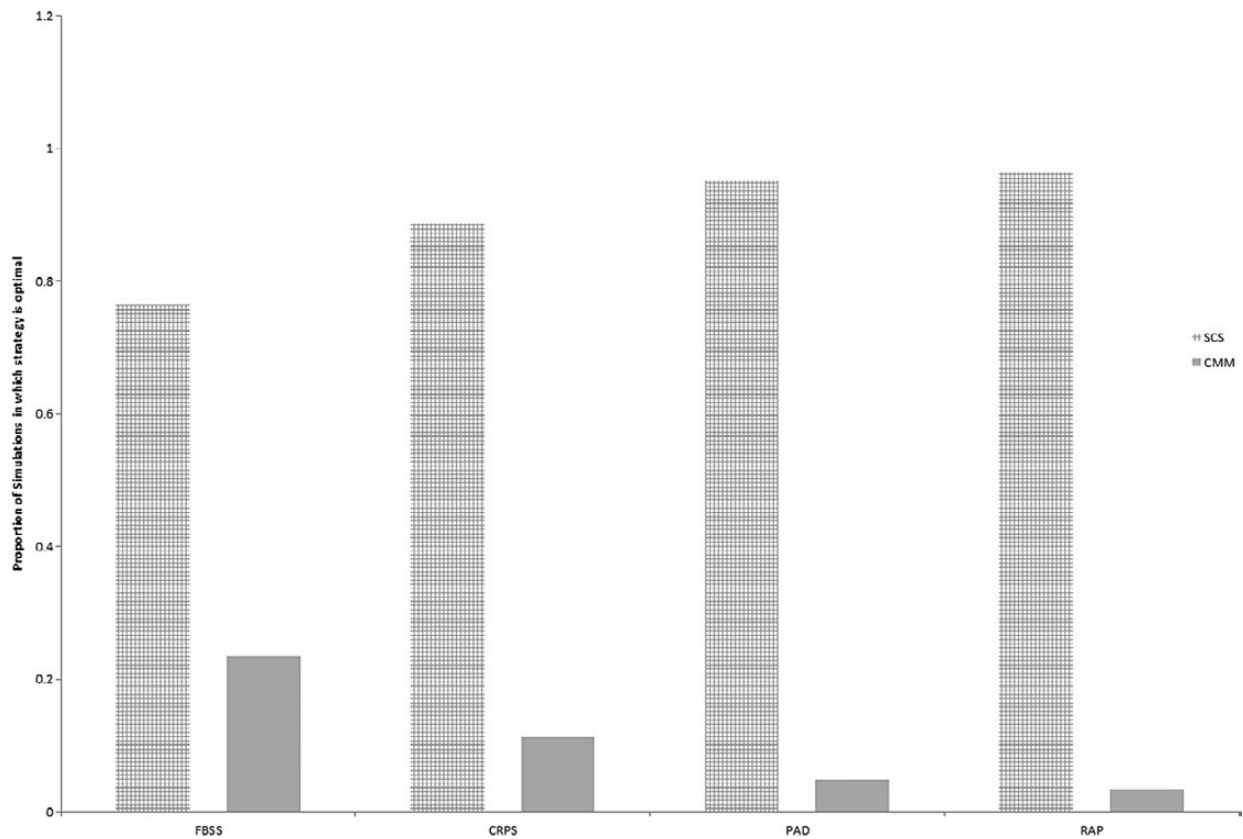
Figure 7 Optimal strategy selection. The majority of simulations indicate that spinal cord stimulation (SCS) is the most cost-effective treatment strategy. FBSS = failed back surgery syndrome; CRPS = complex regional pain syndrome; PAD = peripheral arterial disease; RAP = refractory angina pectoris; CMM = conventional medical management.

Simpson et al. estimated costs and utility scores for SCS and percutaneous coronary intervention (PCI). At 6 years, patients appropriate for PCI incurred a cost of £12,183 with a utility score of 0.65 and gain of 2.93 QALYs vs a cost of £16,857 for the SCS+CMM group with no utility score or QALY provided [25]. To the best of our knowledge, there is no literature that directly compares SCS with PCI stenting—whether bare metal or drug-eluting stents are considered—for RAP.

Despite demonstrated clinical efficacy, SCS remains underutilized for RAP [48]. This can be attributed in part to misperceptions that SCS may mask anginal pain secondary to impending myocardial ischemia and increase the incidence of ventricular arrhythmias, despite clear evidence to the contrary [49,50]. While this article helps address the cost-effectiveness rationale for therapy, further advocacy, education, and emphasis on interdisciplinary management are required if SCS is to gain greater acceptance.

Other Disease States and SCS

Presently, there are no published studies on cost-effectiveness for other nonsurgical pathologies such as

radiculopathies and neuropathies for which SCS is used.

Rechargeable vs Non-Rechargeable IPG

Per our findings, if the stimulation requirements of a patient reduce the longevity of a non-rechargeable IPG below 4.25 years, a rechargeable IPG becomes cost-effective. These results are consistent with those reported by Taylor et al. [17]. However, it may be difficult to predict, with absolute certainty, IPG power requirements of an individual patient based on the SCS trial log. If the SCS trial log reveals high power requirements resulting in an anticipated IPG life span of less than 4.25 years, a rechargeable IPG is advisable.

Strengths

This study examines the long-term cost-effectiveness of SCS through the prism of health economics. The strength of our decision analytic models is the utilization of actual cost, effectiveness, and probability measures derived from a large patient population. Furthermore, each model incorporates both optimal and suboptimal outcomes for the

Table 5 A summary of cost-effectiveness studies on spinal cord stimulation (SCS) in comparison with the present analysis

Study	Data source	Comparator	Time horizon	Cost difference between treatment groups	QALYs difference between treatment groups	ICER	Probability of achieving cost-effectiveness with SCS	Comments
FBSS								
This study (Kumar and Rizvi)	Case series	CMM	20 years	CAN$ 12,917	+1.39	$9,293	75% at WTP of CAN$50,000	
Hollingworth et al. [51] (2011)	Observational study	Pain clinic (PC), usual care (UC)		Mean medical cost per SCS patient over 24 months was $52,091. This was $17,291 higher than in the PC group and $28,128 higher than in the UC group			SCS was very unlikely (<5% probability) to be the most cost-effective intervention	The benefits and potential cost savings reported in RCTs may not be replicated in workers' compensation patients treated in community settings
Taylor et al. [17] (2010)	RCT	CMM	15 years	£7,027	+1.25	£5,624	89% at WTP of £20,000	
Simpson et al. [25] (NICE; 2009)	RCT	CMM	15 years	£11,439	+1.25	£9,155	80% at WTP of £20,000; 95% at WTP of £30,000	
CRPS								
This study (Kumar and Rizvi)	Case series	CMM	20 years	CAN$ 23,778	+2.12	$11,216	87% at WTP of CAN$50,000	
Kemler et al. [14] (2010)	RCT	CMM	15 years	£6,994	+1.96	£3,562	87% at WTP of £30,000	SCS was both more effective and less costly than the standard treatment protocol
Kemler and Furnee [13] (2002)	RCT	CMM	1 year	€4,065	+0.18	€22,582	Not reported	
Simpson et al. [25] (NICE; 2009)	RCT	CMM	15 years	£12,041	+0.64	£18,881	99.02% at WTP of £20,000; 99.96% at WTP of £30,000	
PAD/CLI								
This study (Kumar and Rizvi)	Case series	CMM	20 years	CAN$ 15,563	+1.67	$9,319	93% at WTP of CAN$50,000	
Simpson et al. [25] (NICE; 2009)	RCT	CMM	15 years	Not reported	Not reported	Not reported	Not reported	Cost-effectiveness of SCS in CLI is unknown
Klomp et al. [44] (2006)	RCT	CMM	2 years	€7,900	Not reported	Not reported	Not reported	Eight patients need to be treated to save one more leg, together with the higher cost of SCS treatment (about €8,000 per patient), suggests that about €64,000 extra needs to prevent one amputation
Ubbink et al. [45] (2004)	Meta-analysis	CMM	2 years	€8,000	Not reported	Not reported	Not reported	
Klomp et al. [43] (1999)	RCT	CMM	2 years	f17,376	Not reported	Not reported	Not reported	Per-patient costs in the SCS group were 28% higher than the standard group

RAP

Study	Design	Comparator	Time	Cost	QALY	ICER	Probability	Conclusion
This study (Kumar and Rizvi)	Case series	CMM	20 years	CAN$ 22,064	+2.21	$9,984	95% at WTP of CAN$50,000	Cost-effectiveness of SCS in RAP is unknown
Simpson et al. [25] (NICE; 2009)	RCT	CABG	15 years	Not reported	Not reported	Not reported	Gain of +0.0231 QALYs needed to achieve cost-effectiveness at WTP threshold of £20,000	
Andrell et al. [18] (2003)	RCT	CABG	2 years	−€2,400	Not reported	Not reported	Not reported	The SCS group had fewer hospitalization days related to the primary intervention ($P < 0.0001$) and fewer hospitalization days due to cardiac events ($P < 0.05$)
Dyer et al. [47] (2008)	RCT	PMR	2 years	£5,520	+0.12	£46,000	30% at WTP of £30,000	For patients recruited during 2000/01, the ICER was estimated at £230,000 per QALY (95% CI: −£2,670,000 to £590,000) whereas for 2002/03, the ICER was estimated at £18,000 per QALY (95% CI: −£21,000 to 51,000). This improvement can largely be explained by better outcomes, in terms of survival and QoL, experienced by SCS patients in the second half of the study
Rasmussen et al. [52] (2004)	Case series	TENS	1 year	−$4,473	Not reported	Not reported	Not reported	SCS is effective in reducing the sum of hospital and non-hospital related expenses and improving quality of life of RAP patients, even when implantation costs are included, when comparing the year before TENS treatment to the year after implantation of the SCS system

CI = confidence interval; CLI = critical limb ischemia; CMM = conventional medical management; CRPS = complex regional pain syndrome; FBSS = failed back surgery syndrome; ICER = incremental cost-effectiveness ratio; PAD = peripheral arterial disease; QALY = quality-adjusted life year; QoL = quality of life; RAP = refractory angina pectoris; RCT = randomized control trials; TENS = transcutaneous electrical nerve stimulation; WTP = willingness to pay.
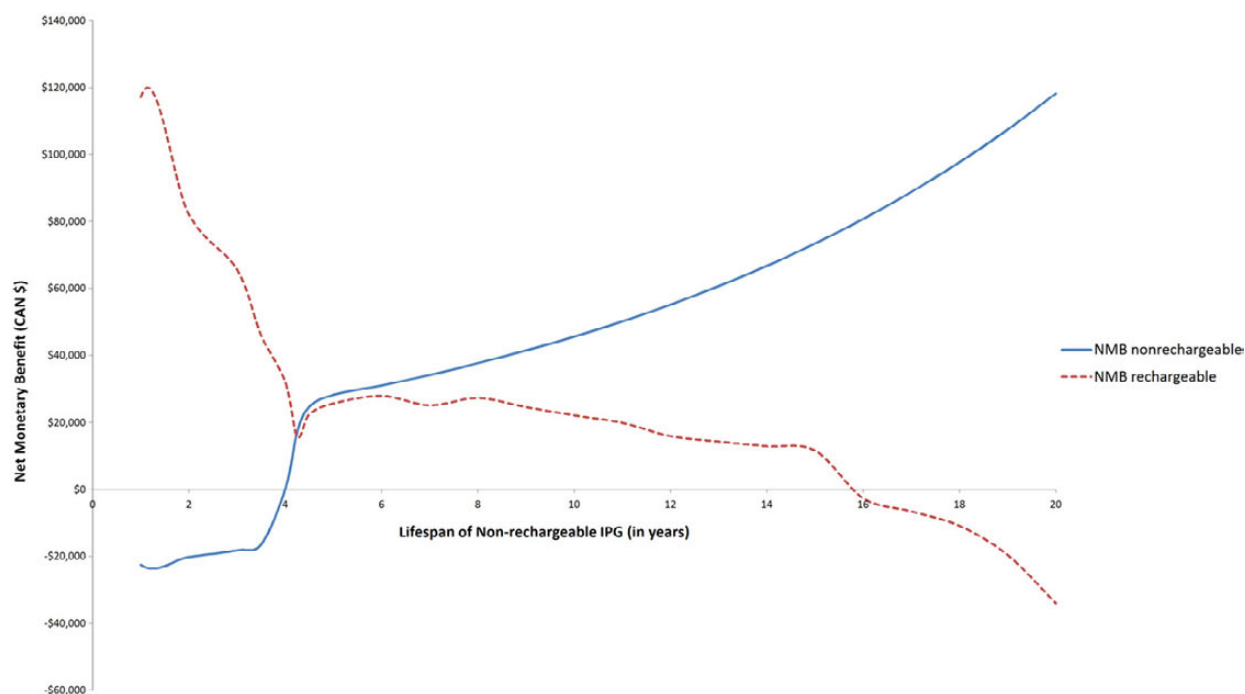
Figure 8 A comparison of the net monetary benefits (NMB) of a non-rechargeable and rechargeable spinal cord stimulation implantable pulse generators (IPG) system. When the longevity of a non-rechargeable IPG is less than 4.25 years, a rechargeable (initially more expensive) IPG is more cost-effective than a non-rechargeable IPG.

SCS and CMM strategies, thus closely emulating clinical reality. It is encouraging that our results are in concordance with previously published cost-effectiveness analyses which were derived from prospective RCTs [14,17].

Limitations

The time horizon of our decision analytic model is 20 years, whereas chronic pain is a lifelong process. Given the lack of outcome data on SCS cohorts beyond this period, we were hesitant to extend our modeling time frame. Another limitation is that the data for this study are derived from a single center. As is the case with all decision models, it is assumed that the two strategies compared are mutually exclusive. The deterministic sensitivity analyses within the decision model are also a limitation in that we were only able to examine the variability in one parameter at a time while assuming that all of the other variables would stay constant. By design, the model did not account for all of the possible pathways in assessment and treatment.

In this study, the efficacy of SCS is based on case series data which may lead to possible overestimation of treatment effect and the possibility of selection bias. Higher quality clinical data will become available only through sufficiently powered RCTs with long-term follow-up. This study would help to improve the design of such prospective, comparative clinical trials.

Conclusions

SCS is cost-effective in the management of neuropathic and ischemic pain states. Significant cost savings can be achieved with the use of this therapy compared with CMM. Clinicians, researchers, and advocacy groups must continue to evaluate treatment efficacy, cost-effectiveness, and economic trends in determining patient access to treatment.

Authorship Description and Acknowledgment

Drs. Krishna Kumar and Syed Rizvi designed and conducted the study including data collection and analysis. Both authors participated in the preparation and approval of the manuscript.

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