

The Evolution of Surgical Technique in Spinal Cord Stimulation: A Scoping Review

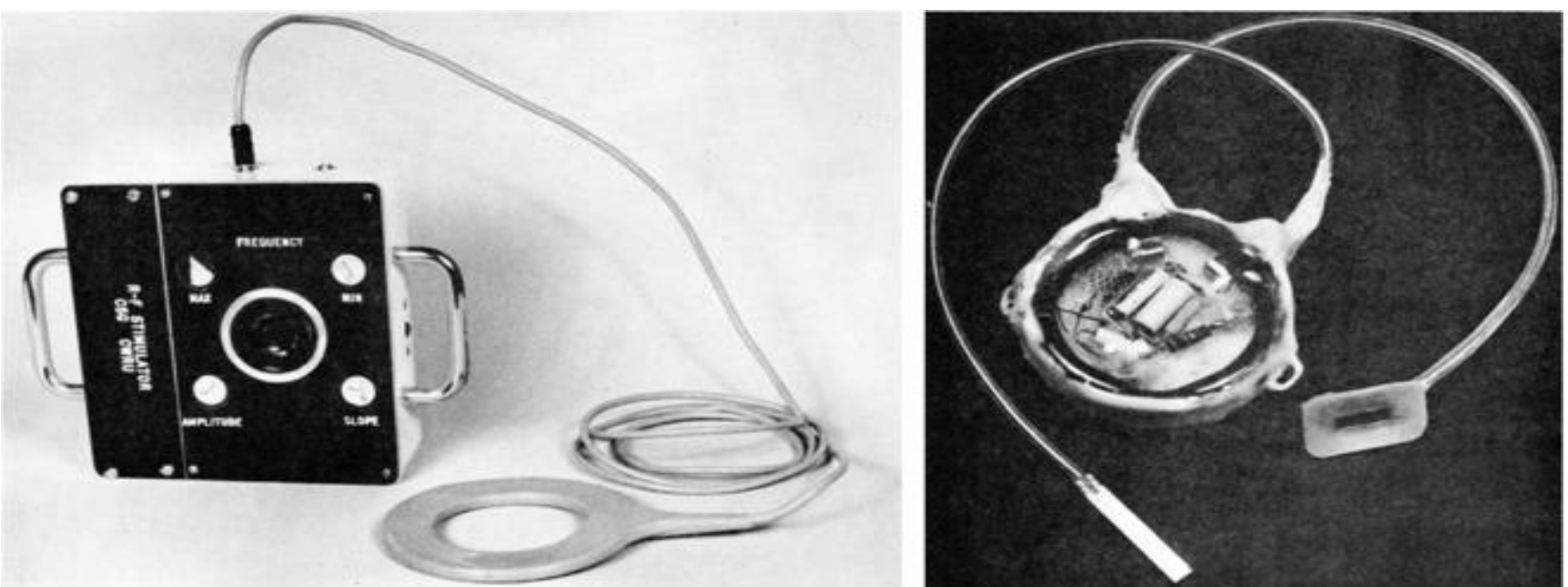
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Background

- Dr. C. Norman Shealy performed the first SCS implantation procedure in 1967, based on the principles of Melzack and Wall's gate control theory of pain.



Radiofrequency SCS system implanted in 1967¹

- In the years since, SCS therapy has been used to successfully treat a variety of painful conditions including: failed back surgery syndrome (FBSS), complex regional pain syndrome (CRPS), refractory angina pectoris, peripheral vascular disease, non-surgical back pain, and diabetic neuropathy.

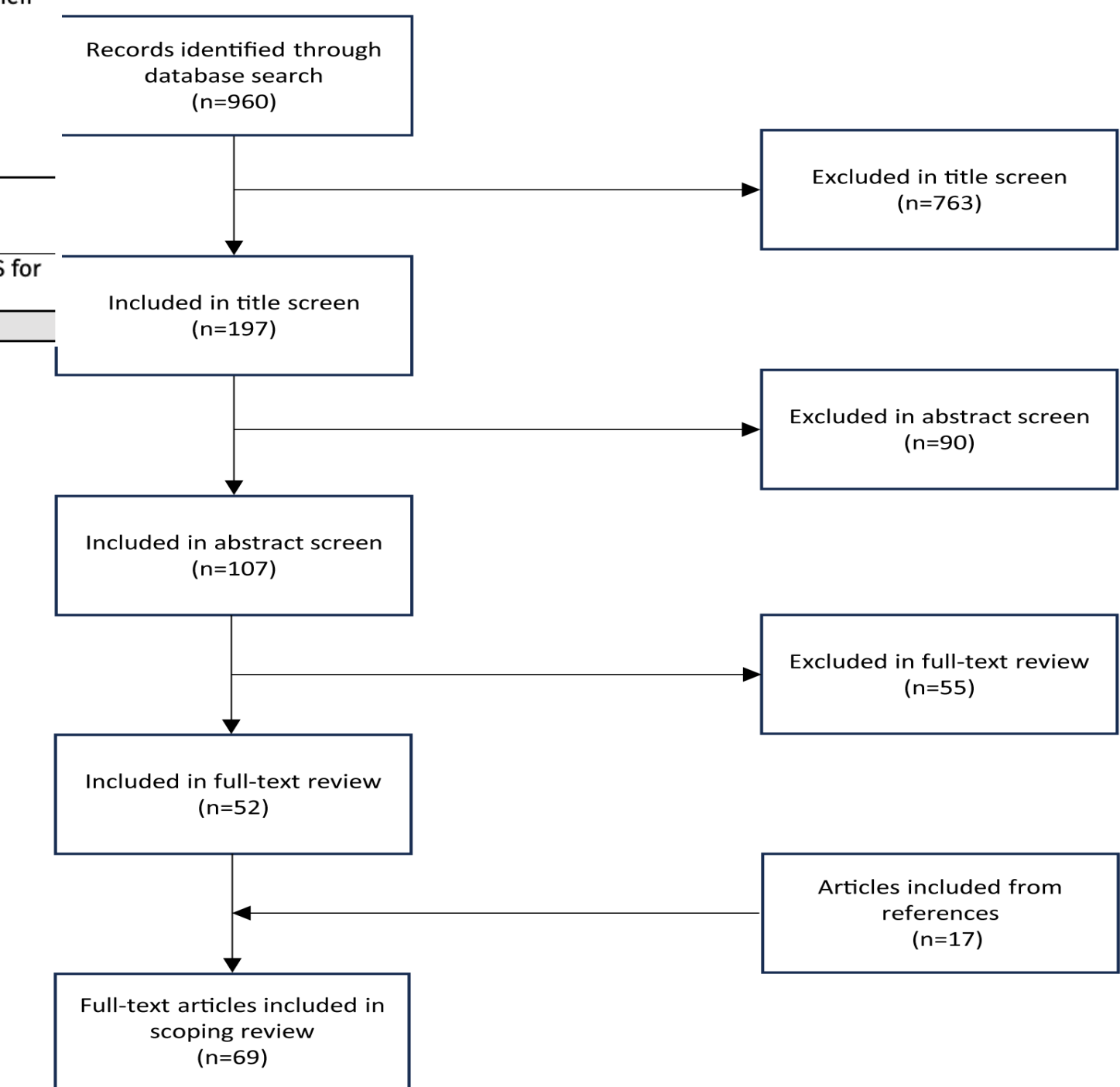
- In addition to the expansion of SCS indications, its hardware and surgical techniques have evolved over time.

- We performed a scoping review of the literature regarding SCS operative techniques with the purpose of reviewing, summarizing, and highlighting key changes in SCS implantation techniques

Methods

- Using the Rayyan platform, two reviewers performed a blinded title screen. Of the 960 articles, 197 were selected for title screen, 107 for abstract review, and ultimately 69 articles met inclusion criteria.

Figure 1. Screening Results Flowchart



- We performed a MEDLINE search of articles from 1967 to June 2023.

Table 1. Search Strategy for Scoping Review

Topic	Search Terms	Rationale for Inclusion
Spinal cord stimulation	((“electric” stim” AND “spinal”) OR “dorsal column stimulat” OR “spinal cord stimulat”)	To capture papers focused on SCS
AND		
SCS trials and implantation techniques	(trial* OR awake OR conscious OR “conscious sedation” OR “anesthetized” OR “general anesthesia” OR neuromonitor OR “intraoperative neurophysiological monitoring” OR emg OR electromyography OR ssep OR “evoked potential” OR MEP OR percutaneous OR paddle* OR lead* OR paresthesia* OR “anatomic landmark” OR “anatomic” OR batter* OR charge* OR recharge* OR anchor* OR laminectom* OR laminotom* OR incision* OR pocket*)	To capture the evolution of SCS trials and permanent implantation procedures over time, including: Changes in the trial period Changes in intraoperative monitoring Changes in SCS lead types, batteries, and their placement Changes in permanent SCS implantation techniques
Sedation and neuromonitoring used during SCS implantation		
SCS leads and batteries		
Paresthesia vs. anatomic landmarks for lead placement		
AND		
Chronic Pain	pain	To broadly capture papers focused on using SCS for chronic pain
Filters used: English language, adults, humans		

We included:

- Papers written in English that involved treating chronic pain in adults and provided information regarding changes, trends, or innovations that impact the workflow of physicians implanting SCS devices for chronic pain management.

We excluded:

- papers that focused on changes in programming or hardware that did not significantly affect device implantation technique or focused solely on revision technique.

Results

Evolution of Trialing in SCS

Reference	Year	n	Type	Trial Length	Results
Hosobuchi et al.	1972	34	Perc.	NR	8/34 found paresthesia intolerable and did not have implant 5/34 had no pain relief with trial
Erickson	1975	16	Perc.	2-3 days	10/16 had satisfactory pain relief during their trials 7/16 proceeded to permanent implantation 1/7 had acceptable pain relief at 8-12 months f/u
Urban et al.	1978	20	Perc.	2 weeks	10/20 did not have adequate relief 6/10 with implants had long-term relief
North et al.	1991	62	Perc.	3-5 days	54/62 of screened patients received a permanent implant Significant association between pain relief and paresthesia overlap
Weinand at al.	2003	54	Perc. (n=33) Pad. (n=21)	15 mins 5 days	53/54 experienced >50% pain reduction in the intraoperative screening 47/54 experienced >50% pain reduction in the 5-day screening
North et al.	2007	*	*	*	Screening trials (3-8 days) are the most important sign in patient selection
Chincholkar et al.	2011	40	Perc. (n=36) Pad. (n=4)	3-28 days	30/40 made their decision by day 9 of trial stimulation Mean duration of failed trials was 8.8 days Mean duration of successful trials was 5.3 days
Padwal at al.	2014	45	Perc.	3-7 days	27/45 had >50% VAS pain reduction Trial-to-implant ratio ~ 60%.
Colombo et al.	2015	122	Perc. (n=49) Pad. (n=73)	15-21 days	89/122 had trial 33/122 did not have trial No significant difference in VAS values between the two groups
Gopal et al.	2016	80	Perc.	< 30 mins	79/80 had a successful on-table trial 32/80 did not need pain medication at 12-month f/u Mean baseline NRS 7.6; 3.9 and 1.6 at 1- and 12-month f/u, respectively
North et al.	2020	99	Perc.	30 days	88/99 had successful single-stage wireless trial 1/99 developed a surgical-site infection during the RCT
North et al.	2020	174	Perc. (n=58) Pad. (n=122)	0-56 days	Significantly higher surgical site infection rates in Belgium (21.7%) compared to other countries participating in the study (1.6%) Trial duration was the only variable that significantly correlated with infections Patients with > 10-day trial had an infection incidence of 24.1% vs. 1.4%
Eldabe et al.	2023	105	Perc.	5-22 days	Trial and no trial groups had significant reductions in mean NRS scores No significant difference in NRS score reduction between the two groups NR= not reported

Perc. = Percutaneous; Pad. = Paddle; f/u = follow-up; * = Evidence-based literature review and consensus statement NR= not reported

Evolution of Intraoperative Neuromonitoring in SCS

Author	Year	n	Lead	Anesthesia	Monitoring	Results
Hosobuchi et al	1972	34	Perc.	Awake	P.M.	Defined concept of awake trial Demonstrated used of paresthesia mapping
Yingling et al	1986	16	Pad.	Asleep	SSEP	Defined concept of asleep trial with antidromic recordings
Hallstrom et al	1991	7	Perc.	Awake	SSEP	SSEP recorded by peroneal nerve as baseline in non-painful leg and confirmed as accurate during implant
Lind et al	2003	19	Pad.	Awake	P.M.	Paresthesia can be mapped under spinal anesthesia
García-Pérez et al	2007	31	Pad.	Awake	P.M.	Patients did not report notable pain/anxiety during procedure
Balzer et al	2011	44	Pad.	Asleep	SSEP	Successful collision studies in 75%, 100% with unilateral pain, bilateral pain, respectively; 100% pain coverage post-operatively
Penar et al	2011	1	Pad.	Asleep	CEP	Demonstrated success of CEP in SCS placement validation
Shils et al	2012	155	Pad.	Asleep	SSEP EMG	VAS scores were reduced 52.11% post operatively 24/151 had lead repositioned due to EMG findings
Air et al	2012	19	Pad.	Asleep	CMAP	Demonstrated CMAPs can be used to define midline 19/19 with good post-operative coverage; 1/19 needed revision
Roth et al	2015	73	Pad.	Asleep	EMG SSEP	51/73 had improvements in MPQ, ODI, PCS, VAS at 6 months 36/73 had improvements in MPQ, ODI, PCS, VAS at 12 months
Tamkus et al	2015	111	Pad.	Asleep	EMG SSEP	In 6 cases, SSEP changes occurred. 2 occurred with lead placement and resolved when lead was removed; 4 were reversed by a change in arm position.
Falowski et al	2019	30	Pad.	Asleep (n=19) Awake (n=11)	EMG	Op. time and OR time shorter for asleep group Asleep group had better pain- paresthesia overlap and less extraneous paresthesia at 6 weeks Equivalent pain relief at 6- and 24-weeks 2 adverse events in the asleep group, 6 in the awake group
Hwang et al	2019	46	Perc.	Asleep	EMG	Mean Op. time and OR time 62 minutes, 147 minutes, respectively Significant improvement in NRS, MPQ, ODI, PCS at 22 months 85% patient satisfaction with device; 17/24 decreased opioid use

Perc. = Percutaneous; Pad. = Paddle; P.M. = paresthesia mapping; CMAP = Compound Muscle Action Potential; VAS = visual analog scale; MPQ = McGill pain questionnaire; ODI = Oswestry disability index; PCS = pain catastrophizing scale; Op. = operative; OR= operating room; NRS= numerical rating scale

Results



Examples of percutaneous SCS leads (LEFT) and paddle SCS leads (RIGHT).²

- The flank region as a site for IPG was first described in 1978 and continues to be a commonly used.

- Implanters had to develop techniques for rechargeable battery implants as these must be approximately 2cm beneath the skin.

- Lead implants have evolved from a single platinum electrode to a wide selection of percutaneous leads and multi-column paddles placed largely between T8-T10

- Transition from four-contact percutaneous systems to eight-contact leads occurred and demonstrated a better long-term pain relief and greater quality of life and sleep improvement.

- While paddle anchors remain similar to those used over the past two decades, percutaneous anchors have improved to reduce migration.
 - This was done by pushing the nose of the anchor to through the fascia and secured with a 2-0 non-absorbable suture.

Conclusion

SCS has evolved in design, insertion technique, and even purpose over the last 50+ years.

Due to innovations and collaboration of neuromodulators with industry, SCS is continually becoming safer and more effective for patients suffering from chronic pain.

Physicians implanting SCS systems for chronic pain management must continually refine their surgical techniques to keep up with the rapidly evolving therapy.

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Disclosure

Dr. Pilitsis receives grant support from Medtronic, Boston Scientific, Abbott, NIH 2R01CA166379, NIH R01EB030324, and NIH U44NS115111. She is the medical advisor for Aim Medical Robotics and has stock equity. RTA receives fellowship support from Medtronic, Abbott and Boston Scientific.