Retrospective Study

Treatment Efficacy and Technical Advantages of Temporary Spinal Nerve Root Stimulation Compared to Traditional Spinal Cord Stimulation for Postherpetic Neuralgia

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Background: Postherpetic neuralgia (PHN) is a common complication after herpes zoster infection. While conventional dorsal column temporary spinal cord stimulation (tSCS) has been shown as an effective treatment option for this pain condition, recent data suggests ipsilateral temporary spinal nerve root stimulation (tSNRS) as a safe alternative for treating PHN. However, there is no direct clinical comparison between the newer tSNRS and the traditional tSCS.

Objectives: The current retrospective study aimed to describe the technical factors and the therapeutic efficacy of tSNR for patients with unilateral PHN and to compare these parameters with those treated with tSCS.

Study Design: Retrospective cohort study.

Setting: Single-center study in a large academic hospital.

Methods: One hundred sixty patients with unilateral PHN who underwent 7-14 days of tSCS (n = 109) or tSNRS (n = 51) treatment were included. Technical factors between the 2 groups, such as procedure time, radiation dosage, number of electrodes used, number of stimulation parameter adjustments, and average cost, were compared. Treatment efficacy, measured by analgesic coverage, pain visual analog scale (VAS), total analgesic agent consumption, Pittsburgh sleep quality index (PSQI), and physical and mental quality of life, were also compared between the 2 groups at baseline, post-procedure, and 3 months after stimulation treatment.

Results: Patients who underwent tSNRS reported significant improvement in pain level, sleep quality, and overall quality of life immediately postprocedure and during the follow-up period. This therapeutic effect was comparable to the tSCS group. Moreover, tSNRS achieved this therapeutic effect with a fewer number of implanted electrodes and stimulation adjustments than tSCS. The precision and consistency of the tSNRS technique were associated with a significant overall lower cost, a shorter procedure time, and less intraoperative radiation exposure in the tSNRS group than in those who received tSCS.

Limitations: The current retrospective cohort study was limited by its relatively short follow-up period. Also, the selection of stimulation techniques was not randomized.

Conclusions: While tSNRS provides similar therapeutic efficacy compared to tSCS for patients with unilateral PHN; it offers several technical advantages. These advantages include shorter procedure time, less radiation exposure, fewer implanted electrodes, more effective stimulation, and lower overall cost.

Key words: Postherpetic neuralgia, temporary spinal cord stimulation, temporary spinal nerve root stimulation, neuromodulation technique, efficacy, retrospective study, safety

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Postherpetic neuralgia (PHN), defined by persistent pain lasting more than 30 days after the resolution of herpes zoster infection, is a common complication in patients over 50-years-old (1-5). The risk factors for PHN include immunosuppression, diabetes mellitus, and advanced age (3,5,6). With the estimated prevalence of 10-15% at age 50 for herpes zoster patients, the relative risk increases by 1.3 to 2.4 times per 10-year interval (3,6). Given the chronic nature of PHN, it is often associated with depression, anxiety, poor sleep quality, and declined physical activity, which together can significantly impact a PHN patient's quality of life (7,8).

Unfortunately, achieving optimal symptomatic relief for patients with PHN is challenging. Topical lidocaine and capsaicin have limited efficacy except for treating mild PHN pain (9,10). A limited number of pharmacological agents, such as opioids, anticonvulsants (e.g., gabapentin, pregabalin), and tricyclic antidepressants, are commonly used for moderate to severe PHN pain, although their efficacy varies among individual patients (1,4,5,11-14). Furthermore, given the age group of many PHN sufferers, some of these agents are not well-tolerated in patients with multiple co-morbidities (e.g., renal or hepatic impairment) (15).

In the effort to reduce polypharmacy and to provide treatment for those who failed pharmacotherapy, spinal neuromodulation techniques have been utilized for PHN (16,17). The precise mechanism of spinal cord neuromodulation leading to dermatomal pain relief remains uncertain, but it is thought that stimulation of the spinal dorsal column interferes with spinal dorsal horn nociceptive transmission through activation of A-beta and A-alpha afferent input – a mechanism known as the "gate-control theory" (16,18,19). Case series of temporary dorsal column spinal cord stimulation (tSCS) have shown success in providing symptomatic relief and significant improvement in quality of life for patients with PHN (20-25). However, the spinal dorsal column anatomy could limit the efficacy of single-electrode tSCS due to the higher likelihood of lead migration, ineffective deep structure stimulation, and incomplete or excessive paresthesia coverage (26-28). Thus the 2-electrode dorsal column approach is often required to achieve an adequate therapeutic effect (19).

Responding to the limitations posed by the traditional tSCS technique, the temporary spinal nerve root stimulation (tSNRS) technique was developed (27,29). This technique aims to directly stimulate specific nerve roots, which could reliably provide paresthesia restricted to the targeted dermatomes without triggering unwanted stimulation elsewhere (27,29). Furthermore, effective stimulation can often be achieved by a single electrode in tSNRS (26,27). This could translate to a more efficient electrode implantation process and better coverage than a single electrode tSCS. Recent data suggest the tSNR technique can provide a similar degree of pain relief as tSCS for patients with various neuropathic pain conditions, including PHN (26,30-33). However, the current data are limited to case reports and case series, and there is no direct comparison between tSNRS and tSCS on their technical parameters and clinical efficacy.

The current single-center, retrospective cohort study aimed to bridge this knowledge gap. Clinical data from 160 PHN patients who underwent either tSCS or tSNRS were analyzed. Their respective outcomes during the immediate postoperative period and the subsequent 3-month follow-up were compared. Technical parameters of the 2 techniques were also evaluated including procedure time, radiation exposure, number of stimulation adjustments, and overall cost of the treatment,.

Methods

Patient Demographic and Selection

The current study was approved by the Ethics Committee of Shenzhen Nanshan People's Hospital and the 6th Affiliated Hospital of Guangdong Medical University (No. 2016041201).

The medical history, intraoperative records, and the 3-month postoperative records of patients who 1) were unsatisfied with conservative medical therapy (e.g., anticonvulsants, antidepressants) and 2) received either tSCS or tSNRS treatment between August 2014 and August 2020 for PHN were reviewed. Dorsal root ganglion stimulation was not available at the study site, and patients who had received peripheral nerve stimulation were excluded from the study. Those who had truncated tSCS or tSNRS treatment (e.g., less than 7 days of stimulation period) or loss of follow-up were also excluded.

A total of 160 patients were included in the current single-center, retrospective study. Among them, 51 cases received tSNRS, and 109 cases received tSCS. Upon chart review of pretreatment parameters, there was no significant difference between the 2 groups in patient age, gender, pretreatment PHN characteristics, and baseline quality of life. The demographic and clini-

cal characteristics of patients included in the study are summarized in Table 1.

Spinal Electrode Implantation

All procedures were performed fluoroscopically under moderate sedation. Patients were positioned in the prone position, and standard monitors were applied according to the American Society of Anesthesiologists' recommendations (34). The surgical site was scrubbed with chlorhexidine or iodine cleaning solution, and the entire implantation process was performed under sterile conditions. No prophylactic antibiotic was given perioperatively. The process of neuromodulation electrode implantation for tSCS and tSNRS followed the protocol described by Huang and colleagues (28). All proceduralists had over 10 years of clinical experience in pain medicine and spinal stimulation, and the selection of implantation techniques was made based on proceduralist preference independent of the patient's affected dermatome (Table 1).

For the tSCS group, a 1x8-contact electrode (Model 3873, Medtronic Inc., Minneapolis, MN, or Model 3189, Abbott, Plano, TX, based on availability) was implanted in the paramedian position in the epidural space ipsilateral to the affected side, targeting the spinal dorsal column at the affected levels (Fig. 1A-B). A test stimulation was applied, and the electrode placement was considered adequate when the patient reported paresthesia coverage of 80% or greater of the pain area. If a single electrode stimulation in the dorsal column produced inadequate paresthesia (e.g., < 80%) or nonspecific coverage, a second electrode was placed in the epidural space at the same levels, parallel to the first electrode (Fig. 1C-D). Another test stimulation was applied, and electrode positions were adjusted until 80% paresthesia coverage was achieved.

For the tSNRS group, a 1x8-contact electrode was placed in the posterior-lateral epidural space adjacent to the inner edge of pedicles, ipsilateral to the affected side (Fig. 1E-F). The implanted electrode top was positioned targeting the nerve segments of the affected levels. Test stimulations were applied after each electrode position adjustment until an 80% paresthesia coverage was achieved.

After removing trocars, electrodes were anchored with sutures on the skin (Fig. 2). A sterile dressing was applied at the insertion site to maintain, and patient instruction was given to maintain the integrity of the sterile dressing when electrodes were in place. If the insertion site showed signs of wound infection during the postoperative period, electrodes were immediately removed, and the wound was cleaned with chlorhexidine. The number of electrodes used, procedure time, and radiation exposure dosage were recorded. After inpatient observation for clinical effects and potential complications, participation in physical therapy, and education on stimulator self-management, patients were discharged from the hospital after 3 to 7 days.

Spinal Stimulation Protocol

The tSCS or tSNRS was programmed after implantation. Stimulation frequency, pulse width, voltage, and contact polarity were adjusted until satisfactory coverage and pain control was obtained. The range of

Table 1. *Patient demographics and baseline characteristics.*

Characteristic	Group		*P* value	df	t/χ^2
	tSCS (n = 109)	tSNRS (n = 51)			
Age, years (mean ± SE)	69.0 ± 0.8	68.8 ± 1.2	0.9123§	158	0.1103
Pretreatment pain duration, days (mean ± SE)	278.6 ± 52.0	186.5 ± 36.4	0.2513§	158	1.151
Gender, male/female (n)	66/43	28/23	0.499#	1	0.457
Affected side			0.547#	1	0.367
Left, n	50	26			
Right, n	59	25			
Zoster location			0.686#	1	0.163
Chest (n)	50	30			
Lumbar (n)	14	3			
Upper limb (n)	33	10			
Lower limb(n)	10	4			
Other location(n)	2	4			
baseline of VAS scores (mean ± SE)	6.9 ± 0.1	7.0 ± 0.2	0.7759£	-	-0.023
baseline of PSQI scores (mean ± SE)	16.9 ± 0.2	16.6 ± 0.4	0.3118£	-	0.08
baseline of PCS scores (mean ± SE)	35.1 ± 1.2	36.0 ± 1.8	0.84£	-	-0.016
baseline of MCS scores (mean ± SE)	34.1 ± 1.2	34.9 ± 1.8	0.9178£	-	-0.008

§Student's t-test, #Chi-square test, and £Mann Whitney test were performed.

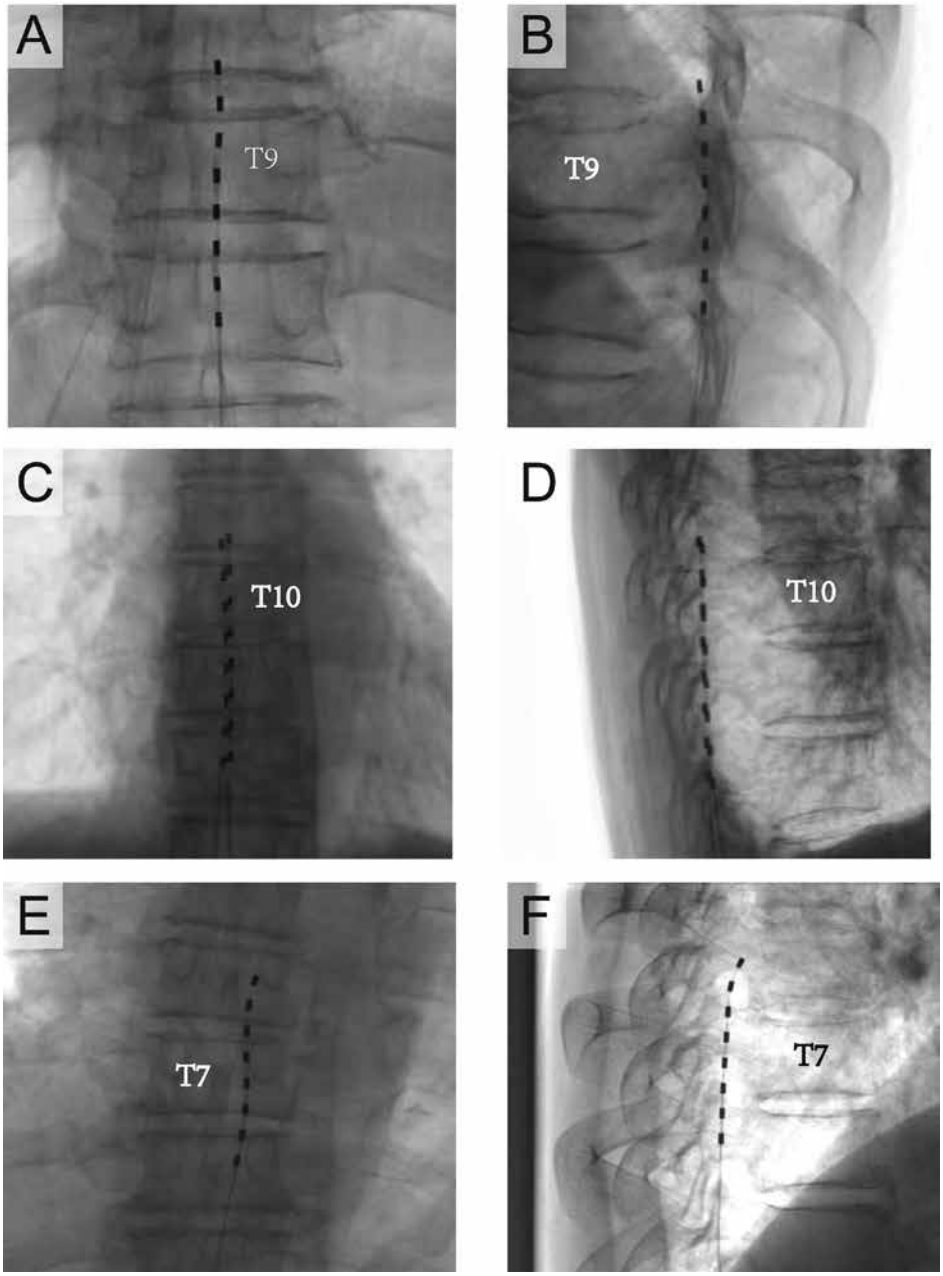

Fig. 1. *Representative intraoperative fluoroscopic images of stimulation electrodes implantation. A) Anterior-posterior and B) lateral view of single tSCS electrode implantation. C) Anterior-posterior and D) lateral view of two tSCS electrodes implantation. E) Anterior-posterior and F) lateral view of single tSNRS electrode implantation.*

frequency was 40-80 Hz, the pulse width was 120-380 milliseconds, and the voltage was 0.5-3 volts. Due to the retrospective nature of the current study, specific stimulation parameters used for each patient were unavailable for analysis. Stimulation remained active for at least 7 days postoperatively. Stimulation parameters were adjusted when the patients felt the area of coverage or pain control was inadequate.

At the end of the initial 7-day stimulation period, the stimulator was paused for 24 hours when the patient reported satisfactory pain relief with normal daily activity or had a personal preference to stop stimulation. If PHN pain relapsed when the stimulator was paused, stimulation treatment would be resumed. If the patient reported sustained pain relief for more than 24 hours without active stimulation, the stimulator would then be turned off permanently.

Regardless of the treatment outcome, all stimulators were turned off on postoperative day 14. The total number of parameter adjustments needed for each patient during the stimulation period was recorded. Electrodes were then explanted under fluoroscopy, and the incidence of electrode migration or fracture was documented.

Assessment of Therapeutic Effect and Follow-Up

Patient-reported outcomes on pain, quality of sleep, and quality of life were assessed immediately after stimulation and monthly during the 3-month follow-up period.

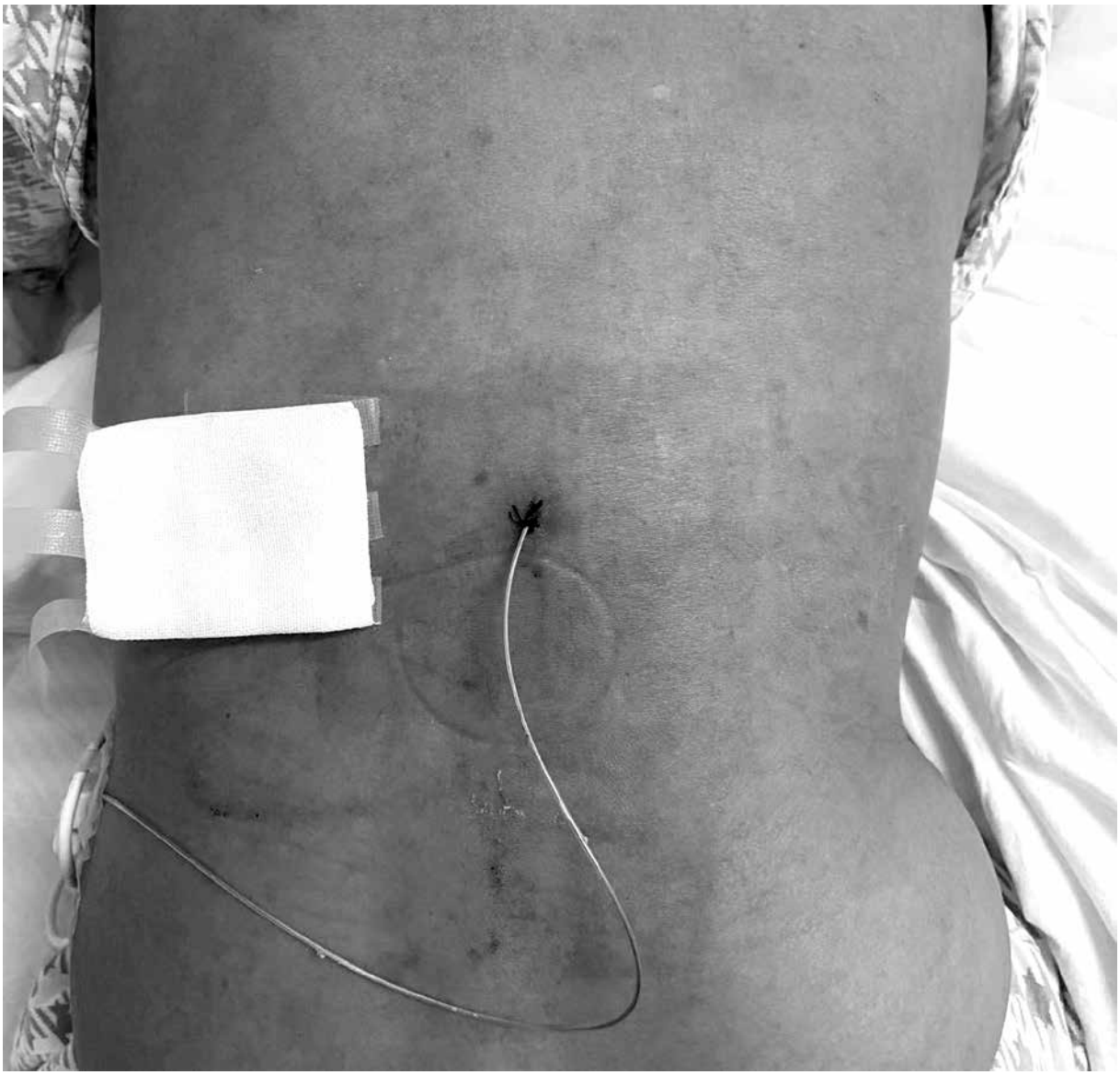

Fig. 2. *An example of electrode sutured at the exit site after trocar removal. The exposed part of the electrode was then secured by sterile gauze and covered by sterile film dressing. Note that no tunneling was performed in the current electrode implant protocol.*

Visual Analog Scale (VAS) was used to measure the severity of PHN pain, where "0" represents no pain, and "10" represents intolerable pain. Patients' sleep quality was assessed using the Pittsburgh Sleep Quality Index (PSQI). The PSQI consists of 7 components, with each being quantified on a 0 to 3-interval scale. The summation of each component score created a global score, which provided an overall assessment of sleep quality. Ranging from 0 to 21, a lower PSQI global score represents a better sleep quality (35). Finally, the patient's quality of life was assessed using the Short Form-36 (SF-36) questionnaire. The SF-36 is divided into physical component summary (PCS) and mental component summary (MCS), which represent physical health and mental health, respectively. The PCS and MCS score range from 0 to 100, where high scores represent better physical and mental well-being and a better quality of life.

Pain area coverage was assessed in each treatment group. The patients' satisfaction was assessed qualitatively at the end of the study period. Patients' satisfaction was qualitatively defined as "comfortable paresthesia covering at least 50% of the painful area and would recommend treatment to a friend." Complications, such as nerve injury, epidural hematoma, cerebrospinal fluid (CSF) leak, wound infection, electrode migration, and electrode fracture, were recorded during follow-up.

Statistical Methods

All statistical analyses and figures were done using Graphpad Prism 8.0 and Microsoft Excel 2010. Friedman test was used to compare between-group differences in VAS, PSQI, PCS, and MCS over time. The difference in the percentage of patients consuming analgesics over time between the tSCS and the tSNRS group was compared using Kaplan-Meier analysis. Student's t-test, Mann-Whitney test, Chi-square, or Fisher's exact test were used to compare patient characteristics, intraoperative parameters, technical differences, and rate of complications between the 2 groups. The detail of the specific test performed for each data set was listed in the corresponding figure legends. Data were presented as the mean ± standard error of the mean. A $P < 0.05$ was considered statistically significant.

Results

tSNRS Was as Effective in Treating PHN as tSCS With Minimal Side Effects

PHN patients who received tSNRS had significant pain relief after the procedure and the 3-month follow-up period (Fig. 3A). They also reported a significant improvement in sleep quality and both physical and

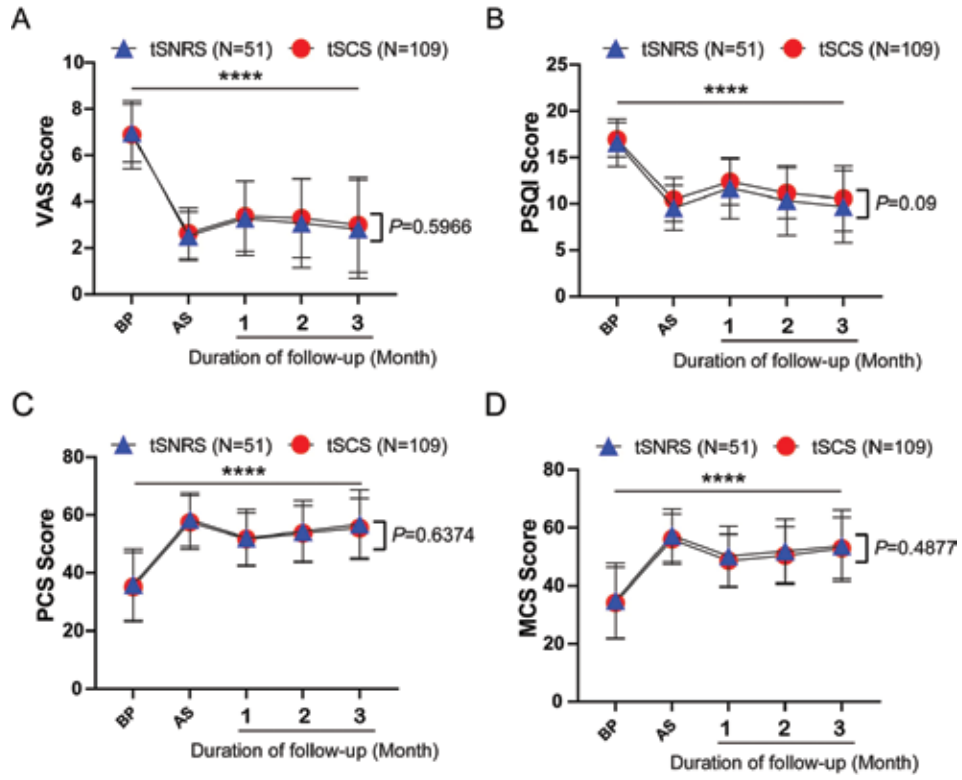

Fig. 3. *Treatment efficacy of tSCS and tSNRS for the PHN patients. There was a significant improvement in A) pain score, B) sleep quality, C) physical and D) mental quality-of-life, assessed by visual analog scale (VAS), Pittsburgh sleep quality index (PSQI), physical component summary (PCS), and mental component summary (MCS) respectively, during the immediately postoperative and 3-month follow-up period after spinal stimulation treatments. No statistical difference was found between the tSNRS and the tSCS group. Friedman's test with repeated measures was performed. **** $P < 0.0001$ indicates statistical significance. BP = before procedure, AS = after stimulation.*

mental quality of life (Fig. 3B-D). This treatment efficacy of tSNRS was comparable to those who received the traditional tSCS treatment (Fig. 3A-D).

Patients from both groups reported a decreased analgesic requirement after their respective procedures and during the 3-month follow-up (Fig. 4). Interestingly, there was a slightly lower anticonvulsant consumption in the tSNR group than in the tSCS group by the third month after the procedure (Fig. 4A). The pain coverage was also similar, with 96% of the tSNRS patients reporting adequate coverage of their PHN pain area and 89% for the tSCS group (Table 2). The survey at the end of the study period showed a high satisfaction rate in the tSNRS group at 90%, similar to the traditional tSCS treatment (Table 2).

The tSNRS method was accompanied by a low

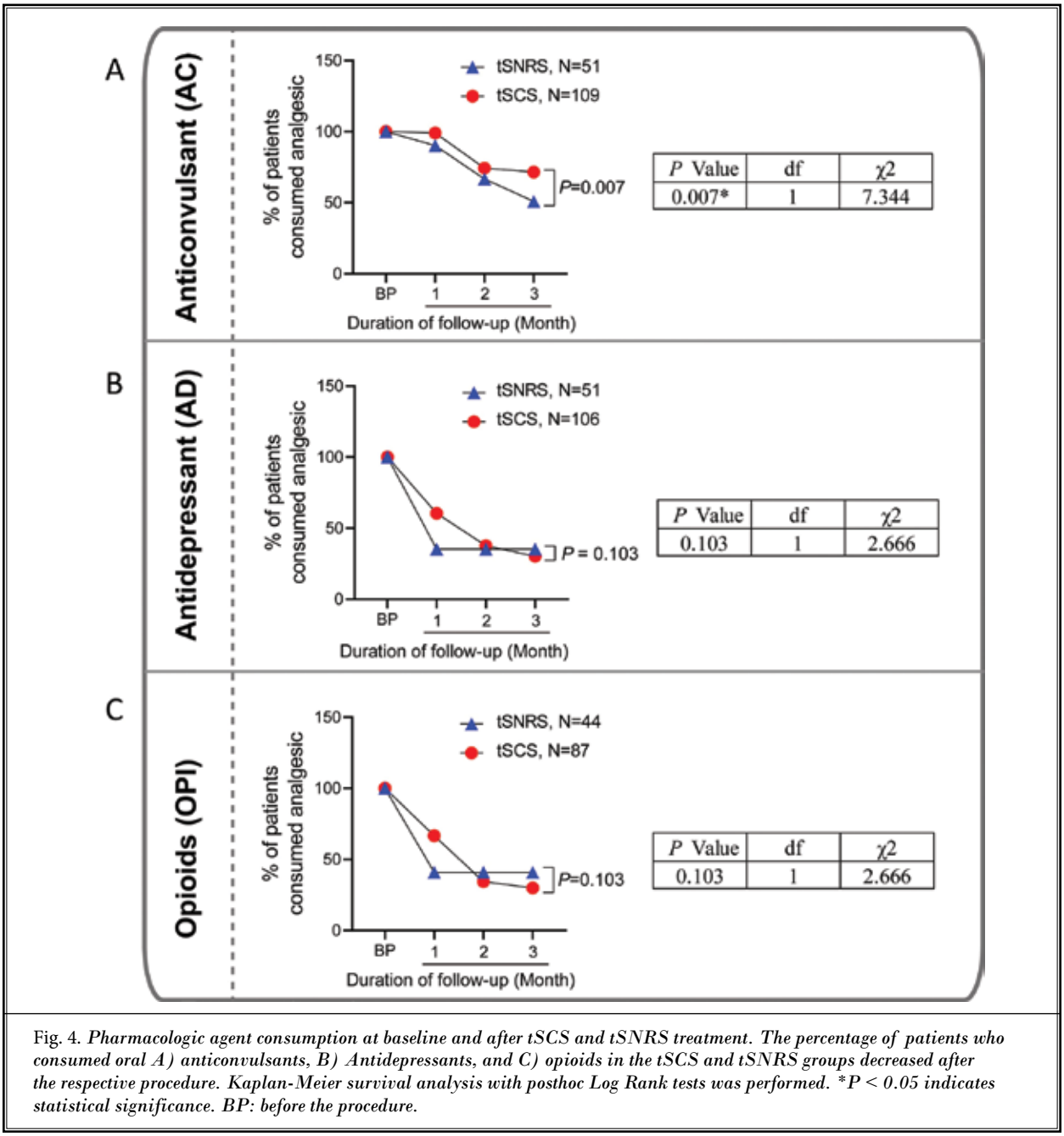

Fig. 4. *Pharmacologic agent consumption at baseline and after tSCS and tSNRS treatment. The percentage of patients who consumed oral A) anticonvulsants, B) Antidepressants, and C) opioids in the tSCS and tSNRS groups decreased after the respective procedure. Kaplan-Meier survival analysis with posthoc Log Rank tests was performed. *P < 0.05 indicates statistical significance. BP: before the procedure.*

Table 2. *Coverage of pain relief and overall patient satisfaction at 3-month follow-up after tSCS or tSNRS treatments.*

	tSCS		tSNRS		*P* value, #	df	χ^2
	n (109)	(%)	n (51)	(%)			
Coverage of pain area					0.1393	1	2.186
Coverage less than the pain area	12	(11)	2	(4)			
Coverage equal to or greater than the pain area	97	(89)	49	(96)			
Patient satisfaction	88	(80)	46	(90)	0.1306	1	2.286

#Chi-square tests were performed.

Table 3. *Summary of postoperative complications after tSCS and tSNRS treatment. Fisher's exact test was performed.*

	tSCS		tSNRS		*P* value
	n (109)	(%)	n (51)	(%)	
Nerve injury	0	(0)	0	(0)	
CSF leak	0	(0)	0	(0)	
Epidural hematoma	0	(0)	0	(0)	
Local Wound Infection	9	(8)	4	(8)	
Electrode migration	11	(10)	5	(10)	
Electrode fracture	0	(0)	0	(0)	
					P = 0.9778

rate of complications. Of the 51 patients who received the procedure, 5 (10%) had radiological evidence of electrode migration, and 4 (8%) had local mild wound infection during the immediate 2-week postoperative period. All cases of wound infection occurred after postoperative day 10, and electrodes were immediately removed according to the study protocol. There was no evidence of long-term infection, nerve injury, CSF leak, epidural hematoma or bleeding, or lead fracture at the end of the study period. There was no statistical difference in complication rate between the tSNRS group and the tSCS group, and all patients tolerated their respective procedures well (Table 3).

The tSNRS Method Was Technically More Advantageous Than the tSCS Method

The levels of implanted electrodes in both groups corresponded to the PHN-affected location of the individual patient. There was no significant difference between the tSCS and tSNRS groups. Notably, not only the tSNRS technique was able to produce similar treatment efficacy as tSCS, but it also required fewer implanted electrodes, shorter procedural time, less radiation exposure, fewer postoperative stimulation adjustments, and lower overall cost than tSCS. The technical details of both procedures are summarized in Table 4.

Discussion

PHN is a debilitating pain syndrome with limited medical treatment options, which could pose a significant toll on a patient's quality of life (1-5). When patients become resistant or unable to tolerate medical therapy, central neuromodulation techniques, such as tSCS and tSNRS, have been independently shown as viable alternatives for treating PHN (20-26). However, most existing evidence came from case series studies with relatively small sample sizes, making a direct comparison between the 2 techniques difficult. The current retrospective single-center cohort study aimed to address this gap in the literature by comparing the postoperative outcomes and the technical parameters between tSCS and tSNRS.

Consistent with previous studies, our current data demonstrated that tSCS was effective in providing, at minimum, a 3-month of pain relief, reduction in analgesic consumption, and significant improvement in overall quality of life for PHN patients (22,24,26,36). Furthermore, all 51 patients who received tSNRS treatment in our study had immediately and sustained improvement in their pain symptoms, an effect that was similar to the tSCS group. This was reflected in the global improvement in patients' quality of sleep and physical and mental well-being. Although small case series had shown the efficacy of tSNRS in several dermatomal pain syndromes, Yanamoto and colleagues were the first to suggest the feasibility of the technique for PHN (26,30-33). Thus, by demonstrating a thorough assessment of its clinical benefits and technical detail with a larger group of patients, the current study further supports the feasibility and the advantages of the tSNRS technique for PHN.

Similar to tSCS, the rate of complications associated with tSNRS was low and overall mild in our current study. Approximately 8% of our patients in both groups had local mild wound infection, which resolved within 2 weeks after electrode removal without long-term sequala. This is consistent with the historic infection rate of 2.5% to 10% for spinal implants, which most could resolve with the removal of implants and

antibiotic therapy (37). Recent data demonstrated that a shorter duration of spinal implants has a substantially lower risk of infection (38). Given the sustained therapeutic effects with either tSNRS or tSCS shown in the current study and the literature, temporary stimulation could be a more favorable neuromodulation technique than its permanent counterpart for PHN (26,30-33). Moreover, future studies for elucidating the role of prophylactic antibiotics for temporary spinal implants could help further decrease the perioperative infection risk.

Electrode migration is also a frequent complication associated with spinal cord electrode implants, with an incidence rate ranging from 2.1% to 27% of all cases (30,31,37,39). Fortunately, the majority of electrode migrations are often minor and do not have significant impacts, as their therapeutic effect can often be reestablished with stimulation reprogramming (37). Consistent with this notion, our patients in both tSNRS and tSCS groups maintained adequate stimulation during the 7 to 14 days of the postoperative stimulation period. Despite the 10% electrode migration rate, our patients in both groups had sustained pain relief and a high satisfaction rate during the 3-month follow-up period.

Table 4. *Comparison of technical parameters between tSCS and tSNRS treatment for PHN.*

Characteristic	Group		*P* value	df	χ^2
	tSCS (n = 109)	tSNRS (n = 51)			
Electrode Locations			0.1423#	1	2.153
Cervical, n (%)	39 (35.8%)	14 (27.5%)			
Thoracic, n (%)	70 (64.2%)	35 (68.6%)			
Lumbar, n (%)	0 (0.0%)	2 (3.9%)			
Number of electrodes used			< 0.0001#	1	24.95
One, n (%)	69 (63.3%)	51 (100.0%)			
Two, n (%)	40 (36.7%)	0 (0.0%)			
Number of stimulation adjustments			< 0.0001#	2	47.59
< 5 (%)	0 (0%)	18 (35%)			
5 -10 (%)	8 (7%)	7 (14%)			
> 10 (%)	101 (93%)	26 (51%)			
			P value	df	z-score
Duration of stimulation treatment (day ± SD)	13.80 ± 0.51	13.76 ± 0.51	0.6982§	158	0.388
Procedural time (min ± SD)	54.00 ± 18.82	37.22 ± 10.84	< 0.0001§	158	5.826
Radiation exposure (mGy ± SD)	119.00 ± 67.31	77.55 ± 27.72	< 0.0001§	158	4.223
Cost of treatment					
Average costs (USD ± SD)	4258 ± 1163	3180 ± 408	< 0.0001§	158	6.4

#Chi-square test and §Student's t-test were performed. *P* value < 0.0001 indicates statistical significance.

Other complications associated with spinal electrode implants documented in previous studies, such as CSF leak, nerve injury, bleeding, and electrode fracture, were not seen in our patients from either group (37,39). Since most of these complications would occur immediately postoperative, it would be unlikely for the patients to develop these complications beyond the 3-month study period. This favorable outcome further supports tSNRS as a safe alternative to tSCS for treating PHN. The length of hospital stay described in the current study was strictly for the abundance of caution. Future studies likely can fast-track discharge for patients who underwent tSCS and tSCS postoperatively, given the relatively low complication rate.

In addition to demonstrating the therapeutic effect of tSNRS, our current data showed a few technical advantages of tSNRS over the traditional tSCS technique. First, the electrode implantation process for tSNRS is more straightforward and efficient than for tSCS. This observation was likely due to single-electrode stimulation of spinal nerve roots could produce a more specific coverage of the affected dermatomes than a single-electrode dorsal column implant for tSCS (19,26-29). Although tSCS could technically overcome this anatomical limitation by implanting a second electrode (19), as seen in the majority of our patients in the tSCS group, it often forced the practitioners and the patients to make intraoperative decisions to implant a second electrode. This led to a longer procedure time, higher cost, and more intraoperative radiation exposure. Therefore, our finding is consistent with the previous report that the electrode implantation technique for tSNRS is more anatomically precise (27,29), which allows for a more targeted neuromodulation than the traditional tSCS. It is important to note that such inconsistency in the SCS electrode implant process could add a layer of uncertainty to patient consent,

cost calculation, preoperative procedural planning, and postoperative care, which could further complicate clinical decision-making, especially when the procedure is performed in an outpatient setting.

Secondly, tSNRS required fewer postoperative stimulation adjustments to achieve sustained pain relief than tSCS. One potential explanation for this observation was that electric field coverage for tSNRS is less susceptible to patient movement. Indeed, with patients flexing and extending their cervical and thoracic spine, the electrodes for tSCS could have inconsistent contact with the targeted spinal level due to the lack of anchoring within the paramedian epidural space (40). On the contrary, since the electrodes for tSNRS were positioned in a much narrower epidural space adjacent to the inner edge of pedicles, they could maintain better contact with the targeted spinal level when patients move (40). This is consistent with the clinical observation by Levine and colleagues, who found SNRS had fewer positional variations in stimulation and clinical effects than SCS (30).

Collectively, our data showed that tSNRS is a viable alternative to the traditional tSCS neuromodulation technique in treating PHN. It provided a comparable level of pain relief as tSCS and improved the overall quality of life for PHN patients. Importantly, tSNRS also offers several technical advantages compared to tSCS, including shorter procedure time, less intraoperative radiation exposure, more consistent stimulation, fewer postoperative adjustments, and lower overall cost. Future studies on technical parameters, such as electrode specification, positioning, stimulation protocol, and postoperative implant care, will further improve the safety and reproducibility of this neuromodulation technique.

There were a few major limitations in this study. First, the current observation was limited by the study's retrospective nature, which led to lacking certain important details, such as individual postoperative stimulation parameters. Secondly, although all proceduralists were experienced in electrode implantation and chronic pain management, the choice of stimulation technique was not randomized. Patient selection was also not randomized due to the retrospective nature of the study. Together, these factors could lead to inherent selection bias based on proceduralist preference and patient self-selection. Furthermore, although the current sample size might be sufficient to show the intermediate-term treatment efficacy, certain long-term outcomes, such as recurrence rate, remained inconclusive due to the relatively short follow-up period in the current study. In addition to long-term follow-up, future studies on the efficacy and safety of repeat tSNRS for patients with recurrent symptoms after an initially successful treatment would also be of great interest, as repeat tSCS appears to be equally effective for other pain conditions (41). Lastly, the expected effect size of the measured outcomes based on the current sample size was difficult to estimate. This was mainly due to the lack of historical data directly comparing the clinical efficacy of the 2 spinal stimulation techniques. Therefore, future prospective randomized control studies with a larger cohort and more extended follow-up period will help better define the long-term treatment efficacy and predict outcomes for PHN patients with different clinical characteristics.

Conclusions

This retrospective study reported tSNRS as an effective alternative treatment to the traditional tSCS technique for PHN patients with additional technical advantages. These advantages include shorter procedure time, less radiation exposure, fewer implanted electrodes, more effective stimulation, and lower overall cost.

Author Contributions

MH performed patient recruitment, data collection, manuscript preparation

QC performed study design, data analysis, manuscript preparation, critical revision

SW, JH, WS, SY performed patient recruitment, data collection, manuscript revision

XQ performed study design, manuscript preparation, critical revision

LX performed study design, manuscript preparation, critical revision, and provided funding support

References

1. Johnson RW, Rice AS. Clinical practice. Postherpetic neuralgia. *N Engl J Med* 2014; 371:1526-1533.
2. Kawai K, Gebremeskel BG, Acosta CJ. Systematic review of incidence and complications of herpes zoster: towards a global perspective. *BMJ Open* 2014; 4:e004833.
3. Helgason S, Petursson G, Gudmundsson S, Sigurdsson JA. Prevalence of postherpetic neuralgia after a first episode of herpes zoster: prospective study

with long term follow up. *BMJ* 2000; 321:794-796.
4. Johnson RW, McElhaney J. Postherpetic neuralgia in the elderly. *Int J Clin Pract* 2009; 63:1386-1391.
5. Cohen JI. Clinical practice: Herpes zoster. *N Engl J Med* 2013; 369:255-263.
6. Forbes HJ, Thomas SL, Smeeth L, et al. A systematic review and meta-analysis of risk factors for postherpetic neuralgia. *Pain* 2016; 157:30-54.
7. Mizukami A, Sato K, Adachi K, et al. Impact of Herpes Zoster and Post-Herpetic Neuralgia on Health-Related Quality of Life in Japanese Adults Aged 60 Years or Older: Results from a Prospective, Observational Cohort Study. *Clin Drug Investig* 2018:38: 29-37.
8. Drolet M, Brisson M, Schmader KE, et al. The impact of herpes zoster and postherpetic neuralgia on health-related quality of life: a prospective study. *CMAJ* 2010; 182:1731-1736.
9. Binder A, Bruxelle J, Rogers P, Hans G, Bösl I, Baron R. Topical 5% lidocaine (lignocaine) medicated plaster treatment for post-herpetic neuralgia: results of a double-blind, placebo-controlled, multinational efficacy and safety trial. *Clin Drug Investig* 2009; 29:393-408.
10. Derry S, Sven-Rice A, Cole P, Tan T, Moore RA. Topical capsaicin (high concentration) for chronic neuropathic pain in adults. *Cochrane Database Syst Rev* 2013; 2:CD007393.
11. Mullan S, Lichtor T. Percutaneous microcompression of the trigeminal ganglion for trigeminal neuralgia. *J Neurosurg* 1983; 59:1007-1012.
12. Hempenstall K, Nurmikko TJ, Johnson RW, A'Hern RP, Rice AS. Analgesic therapy in postherpetic neuralgia: a quantitative systematic review. *PLoS Med* 2005; 2:e164.
13. Huffman CL, Goldenberg JN, Weintraub J, et al. Efficacy and safety of once-daily controlled-release pregabalin for the treatment of patients with postherpetic neuralgia: A double-blind, enriched enrollment randomized withdrawal, placebo-controlled trial. *Clin J Pain* 2017; 33:569-578.
14. Parsons B, Pan X, Xie L, Chen Y, Ortiz M, Whalen E. Comparison of the efficacy and safety of pregabalin for postherpetic neuralgia in Chinese and international patients. *J Pain Res* 2018; 11:1699-1708.
15. Schmader KE, Baron R, Haanpää ML, et al. Treatment considerations for elderly and frail patients with neuropathic pain. *Mayo Clin Proc* 2010; 85:S26-32.
16. Lin CS, Lin YC, Lao HC, Chen CC. Interventional treatments for postherpetic neuralgia: A systematic review. *Pain Physician* 2019; 22:209-228.
17. Aggarwal A, Suresh V, Gupta B, Sonthalia S. Post-herpetic neuralgia: A systematic review of current interventional pain management strategies. *J Cutan Aesthet Surg* 2020; 13:265-274.
18. Oakley JC, Prager JP. Spinal cord stimulation: mechanisms of action. *Spine (Phila Pa 1976)* 2002; 27:2574-2583.
19. Aló KM, Holsheimer J. New trends in neuromodulation for the management of neuropathic pain. *Neurosurgery* 2002; 50:690-704.
20. Liu B, Yang Y, Zhang Z, Wang H, Fan B, Sima L. Clinical study of spinal cord stimulation and pulsed radiofrequency for management of herpes zoster-related pain persisting beyond acute phase in elderly patients. *Pain Physician* 2020; 23:263-270.
21. Iseki M, Morita Y, Nakamura Y, Ifuku M, Komatsu S. Efficacy of limited-duration spinal cord stimulation for subacute postherpetic neuralgia. *Ann Acad Med Singap* 2009; 38:1004-1006.
22. Dong DS, Yu X, Wan CF, et al. Efficacy of short-term spinal cord stimulation in acute/subacute zoster-related pain: A retrospective study. *Pain Physician* 2017; 20:E633-E645.
23. Harke H, Gretenkort P, Ladleif HU, Koester P, Rahman S. Spinal cord stimulation in postherpetic neuralgia and in acute herpes zoster pain. *Anesth Analg* 2002; 94:694-700; table of contents.
24. Moriyama K. Effect of temporary spinal cord stimulation on postherpetic neuralgia in the thoracic nerve area. *Neuromodulation* 2009; 12:39-43.
25. Kurklinsky S, Palmer SC, Arroliga MJ, Ghazi SM. Neuromodulation in postherpetic neuralgia: Case reports and review of the literature. *Pain Med* 2018; 19:1237-1244.
26. Yanamoto F, Murakawa K. The effects of temporary spinal cord stimulation (or spinal nerve root stimulation) on the management of early postherpetic neuralgia from one to six months of its onset. *Neuromodulation* 2012; 15:151-154.
27. Kellner CP, Kellner MA, Winfree CJ. Spinal nerve root stimulation. *Prog Neurol Surg* 2011; 24:180-188.
28. Huang J, Yang S, Yang J, et al. Early treatment with temporary spinal cord stimulation effectively prevents development of postherpetic neuralgia. *Pain Physician* 2020; 23:E219-E230.
29. Haque R, Winfree CJ. Spinal nerve root stimulation. *Neurosurg Focus* 2006; 21:E4.
30. Levine AB, Parrent AG, MacDougall KW. Cervical spinal cord and dorsal nerve root stimulation for neuropathic upper limb pain. *Can J Neurol Sci* 2017; 44:83-89.
31. Levine AB, Steven DA, Parrent AG, MacDougall KW. Successful long-term nerve root stimulation for chronic neuropathic pain: A real world, single center Canadian experience. *Pain Physician* 2017; 20:95-106.
32. Alo KM, Yland MJ, Redko V, Feler C, Naumann C. Lumbar and sacral nerve root stimulation (NRS) in the treatment of chronic pain: A novel anatomic approach and neuro stimulation technique. *Neuromodulation* 1999; 2:23-31.
33. Abbass M, Santyr BG, Parrent AG, MacDougall KW, Staudt MD. Paresthesia-free spinal nerve root stimulation for the treatment of chronic neuropathic pain. *Neuromodulation* 2020; 23:831-837.
34. Hardman MI, Hagedorn JM. Perioperative spinal cord stimulation management: A clinical scenario of device loss and recommendations for anesthesiologists. *Pain Med* 2020; 21:865-867.
35. Buysse DJ, Reynolds CF 3rd, Monk TH, Berman SR, Kupfer DJ. The Pittsburgh Sleep Quality Index: a new instrument for psychiatric practice and research. *Psychiatry Res* 1989; 28:193-213.
36. Oakley JC, Krames ES, Stamatos J, Foster AM. Successful long-term outcomes of spinal cord stimulation despite limited pain relief during temporary trialing. *Neuromodulation* 2008; 11:66-73.
37. Eldabe S, Buchser E, Duarte RV. Complications of spinal cord stimulation and peripheral nerve stimulation techniques: A review of the literature. *Pain Med* 2016; 17:325-336.
38. North R, Desai MJ, Vangeneugden J, et al. Postoperative infections associated with prolonged spinal cord stimulation trial duration (PROMISE RCT). *Neuromodulation* 2020; 23:620-625.
39. Kumar K, Buchser E, Linderoth B, Meglio M, Van Buyten JP. Avoiding complications from spinal cord stimulation: practical recommendations from an international panel of experts. *Neuromodulation* 2007; 10:24-33.
40. Levy RM. Anatomic considerations for spinal cord stimulation. *Neuromodulation* 2014; 17 Suppl 1:2-11.
41. Kemler MA, de Vet HC, Barendse GA, van den Wildenberg FA, van Kleef M. Effect of spinal cord stimulation for chronic complex regional pain syndrome Type I: five-year final follow-up of patients in a randomized controlled trial. *J Neurosurg* 2008; 108:292-298.