



Increased Physical Activity and Reduced Pain with Spinal Cord Stimulation: a 12-Month Study

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ABSTRACT

International Journal of Exercise Science 13(3): 1583-1594, 2020. The purpose of this study was to assess changes in pain and physical activity after replacing a traditional spinal cord stimulation (SCS) implantable pulse generator with a next generation SCS in patients for whom traditional SCS was no longer providing adequate relief of low back and/or leg pain. Subjects ($n = 19$) who reported that they were no longer receiving adequate relief from traditional SCS were implanted with a next generation SCS. Eighteen additional patients who were receiving relief from traditional SCS were also followed as a control. Both groups (next generation, traditional) were assessed for low-back and limb pain (visual analog scale) and daily physical activity (wearable accelerometer) at baseline and three, six, nine and 12 months following the SCS implant. Relative to baseline, next generation SCS subjects exhibited reductions ($p \leq 0.05$ for all) in low-back pain (average reduction of 22%) at every time point, in leg pain (average reduction of 23%) at every time point except six months and increased physical activity (average increase of 57%) at three, six and nine months. As expected, there were no changes in pain or physical activity in the traditional SCS subjects ($p \geq 0.1$). In conclusion, pain decreased, and physical activity increased in patients receiving a next generation SCS. Physical activity may serve as an objectively measured marker of pain.

KEY WORDS: Back pain, physical function, spinal cord stimulation

INTRODUCTION

Chronic pain in the lower back and/or limbs affects millions of Americans (25, 37, 41). Treatments may include, but are not limited to, epidural steroid injections, physical therapy, smoking cessation, weight loss, medications, and surgery (9, 10, 34). While there is evidence supporting the efficacy of these treatments in the management of lower back and/or limb pain, the relief they provide is often short-lived, and/or may require repeated treatments. It is also common, especially in the case of back surgery, that these treatments fail (8).

Because the treatment of low-back/limb pain is complicated and often short-lived, there is a need for novel approaches which may provide enduring relief. While spinal cord stimulation

(SCS) is not a new therapy, advances in medical technology have led to the development of novel SCS devices that warrant investigation (14, 26, 35, 38). SCS therapy, which has been utilized for >40 years, is the surgical implantation of an electrode in the epidural space (14, 26, 35, 38). This electrode is connected to an implantable electrical pulse generator (IPG) which provides electrical stimulation to the spinal cord, stimulating the dorsal column neurons that correspond to the affected area of the patient's pain. This electrical stimulation causes paresthesia in the affected area which reduces pain sensation (30, 38). While multiple studies have demonstrated a significant reduction in lower back and lower limb pain with SCS for patients with failed back surgery syndrome (FBSS) versus those not receiving SCS, these effects can often be incomplete and transient (20, 24, 26, 29). New or next generation SCS units are designed to provide variable stimulation with an algorithm that accounts for the three dimensional space of the leads within the spinal canal (22, 23). As a result, this algorithm may provide a physician the ability to program SCS with greater precision and flexibility compared to traditional SCS systems. This enhanced neural targeting may improve the efficacy of next generation SCS therapy over traditional devices.

While evaluating the efficacy of novel therapies to treat low back pain is warranted, how this research quantifies efficacy is also important to consider. A potential shortcoming of the majority of studies examining low back pain treatments, especially those utilizing SCS, is a focus primarily upon subjective pain scores (14, 35, 38). While pain scores are important when evaluating the efficacy of low back pain treatment, we believe future studies should include greater focus upon objectively assessed functional measures as a way of quantifying medical efficacy. One such functional measure, physical activity, can be assessed objectively and may provide a window into an individual's physical well-being (19). Pain is self-limiting meaning that during a period when an individual is experiencing pain physical activity will typically be limited (2). Therefore, if pain is alleviated, it is likely that physical activity would increase. In this way, physical activity may serve as an objective, albeit indirect, marker for pain.

In addition to being a potential marker for pain, physical activity may also serve as a treatment for individuals with low back pain. Numerous studies have indicated that physical activity is inversely associated with a number of pain disorders including low-back pain, fibromyalgia, diabetes, and migraine (1, 6, 18, 27). In other words, a lack of physical activity is associated with a greater likelihood of having a pain disorder. If pain is alleviated medically and this results in increased physical activity, that greater activity may then have a protective effect against pain resumption (27). There is also evidence that reductions in pain and greater physical activity may have additional positive effects on other measures of psychological health such as anxiety, depression and quality of life which are common problems in individuals with pain disorders (3, 12, 13, 16, 33, 36, 40).

The purpose of this study was to examine the effect of next generation SCS therapy on the following variables: objectively-measured physical activity, self-reported pain, anxiety, depression, and quality of life in a group of patients with low back and/or limb pain for whom traditional SCS was no longer providing adequate relief. In addition to examining a group of patients who had their traditional SCS replaced with a next generation SCS we also followed a group of patients for whom traditional SCS was providing adequate relief. This traditional

group was then compared to the next generation group. The individuals who were satisfied with their traditional device were included as a reference group in the present study as it was hypothesized that these individuals may represent a desired clinical outcome for the patients undergoing revision to next generation SCS. Because they were satisfied with their device, we hypothesized that this group retaining their traditional SCS would report lower pain and be more physically active than the next generation SCS group at baseline. We then hypothesized that these differences would abate over time as the next generation group, relative to baseline, would report decreased pain scores and participate in greater amounts of physical activity. Were these hypotheses to occur and the next generation SCS patients increase physical activity and decrease pain scores to levels that were similar to those who were satisfied with their traditional SCS device, this could be considered a positive clinical outcome for the next generation SCS patients as it pertains to pain scores and physical activity.

METHODS

Participants

Participants were recruited from a pool of patients that were receiving care for low back and/or leg pain and were eligible for removal of a traditional SCS IPG and subsequent re-implantation with a next-generation SCS IPG utilizing three-dimensional neural targeting. These patients had all been implanted with the traditional 16 contact SCS IPG (St. Jude Medical Inc. Rechargeable, St. Paul, MN) ≤ 18 months prior to the start of the present study. Patients were eligible for removal of this traditional SCS as this device was undergoing a factory recall. The initial pool consisted of 103 patients (58.1 ± 12.4 years of age, $n = 49$ female, 54 male) eligible for removal of their traditional SCS IPG and replacement with the next generation SCS IPG (Boston Scientific Precision Spectra™ SCS System, Valenica, CA). Of the 103 eligible patients, 31 elected to undergo surgical revision to the next generation SCS IPG. Only the SCS IPG was replaced and the original leads (which included below percutaneous and paddle leads) were not removed or revised. These 31 patients elected revision to the next generation SCS as they were dissatisfied with the traditional SCS (i.e., it was not providing adequate relief) and not because the traditional device had failed. Of those 31 patients undergoing revision to the next generation SCS device, 19 agreed to participate in this study (55.6 ± 10.2 years of age, 1.70 ± 0.09 m height, 97.6 ± 18.1 kg weight $n = 9$ female, 10 male). Prior research (21) examining the efficacy of the next generation SCS demonstrated a significant reduction in pain (via VAS) from pre-implantation to 12 months post-implantation of $33.6 \pm 12.2\%$. A difference of this size yields an effect size of 2.8. Given this effect size, an α of 0.05 and a power of 0.80, only four pairs of participants would be necessary to demonstrate significance. However, in the prior study the participants did not previously have a SCS device implanted. The magnitude of the improvements for patients in the next generation SCS group in the current study was heretofore unknown. Our current sample size ($n = 19$) of patients implanted with the next generation SCS represents a 4.75-fold greater sample size than was required to demonstrate significant pain reduction in the previous study. Even with attrition by month 12 of the study we still had a sample ($n = 14$) that was 3.5-fold greater than the minimum as indicated by a-priori power analysis. Therefore, we feel that that our sample size was more than adequate to detect any significant changes in perceived pain in the proposed study.

Of the 72 patients that elected to forgo SCS unit revision and keep their traditional device because they were satisfied with the relief they were receiving, 18 agreed to participate in the study (54.8 ± 14.5 years of age, 1.68 ± 0.10 m height, 84.3 ± 15.5 kg weight, $n = 10$ female, 8 male). Written informed consent was obtained from all participants and all procedures and assessments were approved by the University Institutional Review Board. Additionally, this research was carried out fully in accordance to the ethical standards of the International Journal of Exercise Science (28).

Protocol

Baseline assessments were performed after informed consent was obtained. Dependent variables were collected at baseline and three, six, nine and 12 months. Baseline assessments for patients who elected to receive the next generation SCS IPG occurred the week prior to surgical replacement of their traditional SCS device. Baseline assessments for patients who elected to retain their traditional SCS device were taken at the time that they consented to participate in the study. At each visit (baseline, three, six, nine and 12 months) bodyweight, and physical activity, as well as self-reported pain, anxiety, depression, and quality of life were assessed.

Approximately one week after completing baseline assessments, the next generation group ($n = 19$) underwent outpatient surgery to replace their traditional SCS IPG with the next generation SCS IPG. Patients were placed in the prone position with the area over the pre-existing SCS IPG exposed. Monitored Anesthesia Care was provided to ensure patient comfort and standard sterile techniques were used. Adequate location anesthesia was obtained prior to incision. A small incision was created at the previously implanted SCS IPG. Once the current system was identified, the anchoring sutures were removed, and the traditional system expelled from the body. The leads were loosened from the previous SCS IPG with care to not damage them. Those leads were left in and were then anchored into the newly implanted next generation SCS IPG. Impedances and connections were checked by a company representative in the operating room. Once connections were satisfactory, the leads were anchored into place. The next generation SCS IPG was then anchored into the pre-existing tissue pocket followed by multi-layer closure of the fascia and skin. The procedure lasted approximately 40 minutes from incision to closure and there were no adverse incidents.

Bodyweight was assessed to the nearest kg using a balance beam scale (Health O Meter, Chicago, IL) at each visit. At each visit participants were given a validated, wrist-mounted accelerometer (Movband, DHS Group, Houston, TX) to wear for two weekdays and one weekend day, for a minimum of 10 hours each day, during the week after that visit (4). Participants were also given a daily log in which to record the days and times that the accelerometer was worn. Participants then returned the accelerometer and log to the clinic using a postage-paid envelope that was provided to them. Upon receiving the accelerometer in the mail, research personnel recorded the total activity counts per day that the device was worn. Total daily counts across all three days were summed then divided by the total number of minutes that the device was worn over the three days and $\text{counts} \cdot \text{min}^{-1}$ the device was worn was calculated as the measure of physical activity. This process was repeated for each time point (baseline, three, six, nine and 12 months). Assessing physical activity for a minimum of one week day and one weekend day predicts >90% of the variance in total weekly physical activity (39).

Therefore, the current assessment of two weekdays and one weekend days provides a valid assessment of physical activity behavior.

During each visit, participants were asked to report their pain in three separate areas: low back, left leg and buttock and right leg and buttock, utilizing a validated VAS pain scale ranging from 0 ("no pain at all") to 10 ("unbearable, excruciating pain") (32). The two lower-limb scores (left leg and buttock and right leg and buttock) were then averaged and reported as a single lower-limb pain score.

Participants completed the Quality of Life Scale (QOLS) during each visit. The QOLS is a commonly utilized survey for tracking health outcomes for patients with chronic disease such as those with FBSS (17). The questionnaire consists of 16 items that assess the following domains: material and physical well-being, relationships with other people, social, community and civic activities, personal development and fulfillment, recreation and independence (5).

Participants completed the Beck Depression and Anxiety inventories during each visit. The Beck Anxiety inventory consists of 21 items for which patients assign a numeric value to (0, 1, 2, or 3). Those individual numeric values are summed as an index of anxiety. The Beck Depression inventory similarly consists of 21 items to which patients assign a numeric value to (0, 1, 2, or 3). Those values are also summed as an index of depression (15).

Statistical Analysis

Three, six, nine and 12 month results were compared to baseline for each group (traditional, next generation) separately for the following dependent variables: physical activity (accelerometer counts·min⁻¹), pain VAS (lower limb, lower back), body weight, and anxiety, depression and quality of life scores. Independent samples t-tests were then used to compare the next generation participants to the traditional participants at each time point (baseline, three, six, nine and 12 months). T-tests were selected over other analytic techniques (e.g., ANOVA) as there was attrition over the 12-month study. Using the present approach allowed for the analysis of all subjects for the entire time that they participated in the study.

RESULTS

Bodyweight

Participants in the next generation group were significantly heavier than the traditional group at baseline, six, nine and 12 months ($p \leq 0.03$, Cohen's $d = 0.78 - 0.99$, Table 1). There were no significant changes in bodyweight at any time point in either group ($p \geq 0.3$).

Physical activity

Relative to baseline, participants in the next generation group accumulated 77%, 49%, 44% and 53% more accelerometer counts·min⁻¹ at three, six, nine and 12 months, respectively (Table 1). These were significant increases at each time point ($p \leq 0.03$, $d = 0.59- 0.94$) except for 12 months which was trending towards significance ($p = 0.059$, $d = 0.60$). Participants in the traditional group did not significantly alter physical activity nor were there any differences between groups ($p \geq 0.1$).

Lower back pain

Relative to baseline, participants in the next generation group reported 21%, 18%, 28% and 19% reductions in low back pain at three, six, nine and 12 months, respectively (Table 1). These were all significant reductions ($p \leq 0.03$, $d = 0.55 - 0.90$). Participants in the next generation group reported significantly greater lower back pain than the traditional group at baseline ($p = 0.02$, $d = 0.84$) but no other time points. The traditional group did not alter lower back pain scores at any time point ($p \geq 0.3$).

Lower limb pain

Relative to baseline, participants in the next generation group reported 25%, 29% and 24% less limb pain at three, nine and 12 months, respectively (Table 1). These were all significant reductions ($p \leq 0.05$, $d = 0.50 - 0.67$). These participants also reported a 15%, non-significant reduction in pain at six months ($p = 0.1$, $d = 0.39$). Participants in the next generation group reported significantly greater lower limb pain than the traditional group at baseline and six months ($p \leq 0.03$, $d = 0.72 - 1.05$) but no other time points. The traditional group did not alter lower limb pain scores at any time point ($p \geq 0.3$).

Table 1 lists the mean \pm standard deviation for weight, VAS (lower limb and back), and physical activity (counts \cdot min $^{-1}$) for both the next generation and traditional groups at three, six, nine and 12 months relative to the corresponding baseline value. The sample size for each comparison is listed for each group. Note that the sample size did decrease over the course of the study as some participants decided to withdraw from the study as they no longer wished to participate in follow-up appointments.

Table 1. Weight (kg), VAS (lower limb and back), and physical activity (counts \cdot min $^{-1}$).

		Weight (kg)	VAS Pain Low Limb	VAS Pain Low Back	Physical activity (counts \cdot min $^{-1}$)
Next Generation	Baseline ($n = 19$)	97.6 \pm 18.1	5.6 \pm 2.1	7.2 \pm 2.1	7.0 \pm 6.1
	Three months	91.7 \pm 26.0	4.2 \pm 2.1*	5.7 \pm 2.5*	12.4 \pm 10.4*
	Baseline ($n = 18$)	97.4 \pm 18.6	5.5 \pm 2.1	7.2 \pm 2.2	7.3 \pm 6.2
	Six months	97.3 \pm 19.3	4.7 \pm 1.9	5.9 \pm 1.9*	10.9 \pm 7.4*
	Baseline ($n = 16$)	98.8 \pm 19.1	5.6 \pm 2.2	7.2 \pm 2.3	7.1 \pm 6.3
	Nine months	99.5 \pm 20.4	4.0 \pm 2.4*	5.2 \pm 3.1*	10.2 \pm 8.0*
	Baseline ($n = 14$)	97.7 \pm 20.0	5.8 \pm 2.3	7.5 \pm 2.3	6.0 \pm 4.2
	12 months	99.3 \pm 21.6	4.4 \pm 2.5*	6.1 \pm 2.3*	9.2 \pm 6.7
Traditional	Baseline ($n = 18$)	84.3 \pm 15.5†	3.4 \pm 2.2†	5.1 \pm 3.2†	7.2 \pm 4.1
	Three months	84.1 \pm 15.9	3.4 \pm 2.7	4.6 \pm 3.3	7.6 \pm 5.1
	Baseline ($n = 16$)	83.8 \pm 13.7	3.5 \pm 2.4	5.1 \pm 3.2	7.6 \pm 4.0
	Six months	83.4 \pm 14.4†	3.0 \pm 2.4†	4.8 \pm 3.0	9.7 \pm 8.0
	Baseline ($n = 16$)	83.8 \pm 13.7	3.5 \pm 2.4	5.1 \pm 3.2	7.5 \pm 4.1
	Nine months	82.6 \pm 15.8†	3.9 \pm 2.9	4.6 \pm 3.3	7.6 \pm 6.6
	Baseline ($n = 15$)	82.3 \pm 12.8	3.4 \pm 2.4	4.9 \pm 3.2	7.4 \pm 4.5
	12 months	81.0 \pm 16.5†	3.6 \pm 2.5	4.5 \pm 3.4	7.2 \pm 4.7

*Significantly ($p \leq 0.05$) different from baseline. †Significantly ($p \leq 0.05$) different from the next generation group at the same time point.

Quality of life

Participants in the traditional group reported greater quality of life scores than next generation participants at baseline ($p = 0.03, d = 0.75$) but at no other time point (Table 2). Relative to baseline, participants in the next generation group reported a significant, 8% increase in quality of life at nine months ($p = 0.035, d = 0.58$). There were no other differences in quality of life for either group or between groups ($p \geq 0.15$).

Anxiety

Relative to baseline, participants in the next generation group reported reductions in anxiety scores of 31%, 24%, 39% and 26% at three, six, nine and 12 months, respectively (Table 2). These were all significant reductions ($p \leq 0.04, d = 0.53 - 0.85$). Participants in the next generation group reported significantly greater anxiety than the traditional group at baseline ($p = 0.024, d = 0.79$) but no other time points. The traditional group did not alter anxiety scores at any time point ($p \geq 0.3$).

Depression

Relative to baseline, the next generation group reported 23% and 20% lower depression scores at six and nine months, respectively (Table 2). These reductions were statistically significant ($p \leq 0.05, d = 0.55 - 0.62$). These participants also exhibited non-significant decreases in depression of 16% at both three and 12 months ($p \geq 0.06, d = 0.46$). Participants in the traditional group did not significantly ($p \geq 0.1$) alter depression scores nor were there any differences between groups.

Table 2 lists the mean \pm standard deviation for quality of life, anxiety, and depression scores for both the next generation and traditional groups at three, six, nine and 12 months relative to the corresponding baseline value. The sample size for each comparison is listed for each group.

Table 2. Quality of life, anxiety, and depression scores.

		Quality of Life score	Anxiety Score	Depression Score
Next Generation	Baseline ($n = 19$)	70.3 \pm 11.5	21.6 \pm 10.2	16.3 \pm 13.7
	Three months	73.4 \pm 12.9	14.9 \pm 8.0*	13.7 \pm 7.3
	Baseline ($n = 18$)	71.8 \pm 9.5	21.6 \pm 10.5	15.8 \pm 12.2
	Six months	76.9 \pm 15.7	16.4 \pm 9.5*	12.2 \pm 6.7*
	Baseline ($n = 16$)	71.4 \pm 9.3	21.8 \pm 10.8	16.3 \pm 13.1
	Nine months	77.4 \pm 10.8*	13.4 \pm 9.2*	13.1 \pm 6.9*
	Baseline ($n = 14$)	71.3 \pm 8.4	20.4 \pm 10.6	14.5 \pm 12.2
	12 months	77.1 \pm 14.9	15.1 \pm 10.2*	12.2 \pm 7.2
Traditional	Baseline ($n = 18$)	80.4 \pm 16.0†	13.9 \pm 9.5†	11.2 \pm 10.1
	Three months	80.1 \pm 19.1	13.6 \pm 12.1	11.4 \pm 8.8
	Baseline ($n = 16$)	78.8 \pm 16.2	14.7 \pm 9.7	11.8 \pm 10.6
	Six months	80.9 \pm 18.8	14.1 \pm 12.8	13.2 \pm 11.0
	Baseline ($n = 16$)	78.8 \pm 16.2	14.7 \pm 9.7	11.8 \pm 10.6
	Nine months	83.9 \pm 19.7	14.3 \pm 13.3	10.9 \pm 9.6
	Baseline ($n = 15$)	78.3 \pm 16.6	14.7 \pm 10.0	11.9 \pm 10.9
	12 months	81.4 \pm 20.0	12.2 \pm 12.5	11.9 \pm 11.7

*Significantly ($p \leq 0.05$) different from baseline. †Significantly ($p \leq 0.05$) different from the next generation group at the same time point.

DISCUSSION

This is the first study of which we are aware to examine the effect of replacing a traditional SCS IPG, which was no longer providing adequate relief, with a next generation device using three-dimensional neural targeting on objectively measured physical activity, self-reported pain, and psychological well-being. At baseline, before receiving the new device, participants in the next generation SCS group reported greater pain and anxiety than those in the traditional group who elected not to alter their SCS device. After receiving the next generation device, these participants exhibited significant reductions in pain (back and lower limb) ranging from 18-29% and anxiety scores ranging from 24 to 31%, such that they were no longer greater than those for traditional SCS patients. Apart from one time point (six months) for lower limb pain, these improvements in anxiety and pain scores in the next generation group persisted throughout the entire 12-month study. Furthermore, these reductions are either within or exceeded the range of scores for minimum clinically important difference for improvements in both pain (13-85% change) and anxiety (17.5%) (7, 31).

While it is common to assess self-reported pain in interventions designed to treat lower back/limb pain (14, 35, 38), the assessment of physical activity as an outcome is novel. Presently, in the next generation SCS patients, we noted increases in physical activity of 40% or more than baseline at every time point where pain was reduced. Prior research has indicated that a minimally important difference in physical activity can range from ~17 - 29% (11). Therefore, the next generation SCS group's increases in physical activity would exceed this threshold. Each of these increases in physical activity in the present study were statistically significant apart from the 12-month time point which was trending ($p = 0.059$) towards significance. Conversely, those patients in the traditional SCS group exhibited no changes in physical activity or pain. This finding supports our hypothesis that patients would exhibit concomitant reductions in pain and increases in physical activity with treatment.

The pain relief and increased physical activity with next generation SCS revision reported herein is accompanied by additional positive outcomes, including reduced anxiety and depression along with increased quality of life. While these additional changes may be the result of decreased pain, increased physical activity could also positively affect these variables. Increased physical activity, which may aid in maintaining reduced self-reported pain (2), is inversely associated with anxiety, depression and low back pain (3, 13, 16, 36). In other words, individuals who are more physically active often report lower anxiety, depression, and low back pain than their less-active peers. There is also experimental evidence supporting the notion that participating in physical activity can cause an anti-anxiety and anti-depressant effect (36). Physical activity is also positively associated with quality of life (12, 33) such that physically active individuals, relative to their less active peers, exhibit a greater quality of life. Therefore, physical activity may act as a feed-forward mechanism through which the effects of pain relief on these other variables is maintained or enhanced. Even if physical activity is only a marker for decreased pain, this present finding is still potentially important as physical activity can be measured objectively whereas pain is subjective. Providing objective outcomes for the assessment of pain interventions may aid in the study of the efficacy of such interventions.

Future research on the importance of physical activity assessment in interventions designed to provide relief from pain is therefore warranted.

While this study yields novel information, it is not without limitations. Foremost, this was a small sample to begin with and attrition added to this problem. It is important to note that participants who withdrew from the study did so because they did not wish to attend any further follow-up appointments and not because there were any adverse events with either the next generation or traditional SCS devices. Another limitation was participants self-selected which group they would be in. Therefore, this is not a true experiment and our ability to infer causality is limited. Participants in the next generation group were dissatisfied with their traditional device whereas the traditional group was receiving adequate relief. It is not clear why some individuals received adequate relief with traditional SCS, and others did not. Future studies examining the efficacy of SCS unit revision should include larger samples and randomized control and experimental groups.

In conclusion, this is the first study we are aware of to assess the pain-relieving effects of SCS revision from a traditional device to a next generation device which may allow for more specific neural targeting. This is also the first study to assess the effect of any SCS therapy upon objectively measured physical activity behavior. Patients who were no longer receiving adequate relief with traditional SCS therapy exhibited decreased pain, anxiety, and depression and increased physical activity and quality of life after receiving a next generation SCS device. It is possible increased physical activity may be a marker for decreased pain and could provide further relief from symptoms common to patients with low back pain. Future research that utilizes experimental designs and assesses physical activity as an outcome measure of the efficacy of treatments for pain disorders is warranted.

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REFERENCES

1. Andersen LL, Mortensen OS, Zebis MK, Jensen RH, Poulsen OM. Effect of brief daily exercise on headache among adults – secondary analysis of a randomized controlled trial. *Scand J Work Environ Health* 37(6): 547-550, 2011.
2. Asghari A, Nicholas MK. Pain self-efficacy beliefs and pain behaviour. A prospective study. *Pain* 94(1): 85-100, 2001.

3. Azevedo Da Silva M, Singh-Manoux A, Brunner EJ, Kaffashian S, Shipley MJ, Kivimaki M, Nabi H. Bidirectional association between physical activity and symptoms of anxiety and depression: The whitehall ii study. *Eur J Epidemiol* 27(7): 537-546, 2012.
4. Barkley JE, Glickman E, Fennell C, Kobak M, Frank M, Farnell G. The validity of the commercially-available, low-cost, wrist-worn movband accelerometer during treadmill exercise and free-living physical activity. *J Sports Sci* 37(7): 735-740, 2019.
5. Burckhardt CS, Anderson KL. The quality of life scale (qols): Reliability, validity, and utilization. *Health Qual Life Outcomes* 1: 60, 2003.
6. Busch AJ, Webber SC, Brachaniec M, Bidonde J, Bello-Haas VD, Danyliw AD, Overend TJ, Richards RS, Sawant A, Schachter CL. Exercise therapy for fibromyalgia. *Curr Pain Headache Rep* 15(5): 358-367, 2011.
7. Button KS, Kounali D, Thomas L, Wiles NJ, Peters TJ, Welton NJ, Ades AE, Lewis G. Minimal clinically important difference on the beck depression inventory--ii according to the patient's perspective. *Psychol Med* 45(15): 3269-3279, 2015.
8. Chan CW, Peng P. Failed back surgery syndrome. *Pain Med* 12(4): 577-606, 2011.
9. Chou R, Huffman LH. Medications for acute and chronic low back pain: A review of the evidence for an American pain society / American college of physicians clinical practice guideline. *Ann Intern Med* 147(7): 505-514, 2007.
10. Chou R, Qaseem A, Snow V, Casey D, Cross JT, Jr., Shekelle P, Owens DK. Diagnosis and treatment of low back pain: A joint clinical practice guideline from the American college of physicians and the American pain society. *Ann Intern Med* 147(7): 478-491, 2007.
11. Demeyer H, Burtin C, Hornikx M, Camillo CA, Van Remoortel H, Langer D, Janssens W, Troosters T. The minimal important difference in physical activity in patients with copd. *PLoS One* 11(4): e0154587-e0154587, 2016.
12. DiPietro L. The epidemiology of physical activity and physical function in older people. *Med Sci Sports Exerc* 28(5): 596-600, 1996.
13. Forsyth A, Williams P, Deane FP. Physical activity, but not fitness level, is associated with depression in Australian adults. *J Sports Med Phys Fitness* 55(7-8): 845-854, 2015.
14. Frey ME, Manchikanti L, Benyamin RM, Schultz DM, Smith HS, Cohen SP. Spinal cord stimulation for patients with failed back surgery syndrome: A systematic review. *Pain Physician* 12(2): 379-397, 2009.
15. Fydrich T, Dowdall D, Chambless DL. Reliability and validity of the beck anxiety inventory. *J Anxiety Disord* 6(1): 55-61, 1992.
16. Hurwitz EL, Morgenstern H, Chiao C. Effects of recreational physical activity and back exercises on low back pain and psychological distress: Findings from the UCLA low back pain study. *Am J Public Health* 95(10): 1817-1824, 2005.
17. Inoue S, Kamiya M, Nishihara M, Arai Y-CP, Ikemoto T, Ushida T. Prevalence, characteristics, and burden of failed back surgery syndrome: The influence of various residual symptoms on patient satisfaction and quality of life as assessed by a nationwide internet survey in Japan. *J Pain Res* 10: 811-823, 2017.
18. Krein SL, Heisler M, Piette JD, Makki F, Kerr EA. The effect of chronic pain on diabetes patients' self-management. *Diabetes Care* 28(1): 65-70, 2005.

19. Kuffel EE, Crouter SE, Haas JD, Frongillo EA, Bassett DR Jr. Validity of estimating minute-by-minute energy expenditure of continuous walking bouts by accelerometry. *Int J Behav Nutr Phys Act* 8: 92, 2011.
20. Kumar K, Taylor RS, Jacques L, Eldabe S, Meglio M, Molet J, Thomson S, O'Callaghan J, Eisenberg E, Milbouw G, Buchser E, Fortini G, Richardson J, North RB. Spinal cord stimulation versus conventional medical management for neuropathic pain: A multicentre randomised controlled trial in patients with failed back surgery syndrome. *Pain* 132(1-2): 179-188, 2007.
21. Kumar K, Taylor RS, Jacques L, Eldabe S, Meglio M, Molet J, Thomson S, O'Callaghan J, Eisenberg E, Milbouw G, Buchser E, Fortini G, Richardson J, North RB. The effects of spinal cord stimulation in neuropathic pain are sustained: A 24-month follow-up of the prospective randomized controlled multicenter trial of the effectiveness of spinal cord stimulation. *Neurosurgery* 63(4): 762-770, 2008.
22. Laird JH, Parker JL. A model of evoked potentials in spinal cord stimulation. *Conf Proc IEEE Eng Med Biol Soc* 8(10): 6611057, 2013.
23. Lee D, Hershey B, Bradley K, Yearwood T. Predicted effects of pulse width programming in spinal cord stimulation: A mathematical modeling study. *Med Biol Eng Comput* 49(7): 765-774, 2011.
24. Manca A, Kumar K, Taylor RS, Jacques L, Eldabe S, Meglio M, Molet J, Thomson S, O'Callaghan J, Eisenberg E, Milbouw G, Buchser E, Fortini G, Richardson J, Taylor RJ, Goeree R, Sculpher MJ. Quality of life, resource consumption and costs of spinal cord stimulation versus conventional medical management in neuropathic pain patients with failed back surgery syndrome (process trial). *Eur J Pain* 12(8): 1047-1058, 2008.
25. Manchikanti L, Manchikanti KN, Cash KA, Singh V, Giordano J. Age-related prevalence of facet-joint involvement in chronic neck and low back pain. *Pain Physician* 11(1): 67-75, 2008.
26. Medical SA. Spinal cord stimulation for neuropathic pain: An evidence-based analysis. *Ont Health Technol Assess Ser* 5(4): 1-78, 2005.
27. Naugle KM, Riley JL 3rd. Self-reported physical activity predicts pain inhibitory and facilitatory function. *Med Sci Sports Exerc* 46(3): 622-629, 2014.
28. Navalta JW, Stone WJ, Lyons TS. Ethical issues relating to scientific discovery in exercise science. *Int J Exerc Sci* 12(1): 1-8, 2019.
29. North RB, Kidd D, Shipley J, Taylor RS. Spinal cord stimulation versus reoperation for failed back surgery syndrome: A cost effectiveness and cost utility analysis based on a randomized, controlled trial. *Neurosurgery* 61(2): 361-368, 2007.
30. Oakley JC, Prager JP. Spinal cord stimulation: Mechanisms of action. *Spine (Phila PA 1976)* 27(22): 2574-2583, 2002.
31. Olsen MF, Bjerre E, Hansen MD, Hilden J, Landler NE, Tendal B, Hróbjartsson A. Pain relief that matters to patients: Systematic review of empirical studies assessing the minimum clinically important difference in acute pain. *BMC Med* 15(1): 35, 2017.
32. Price DD, McGrath PA, Rafii A, Buckingham B. The validation of visual analogue scales as ratio scale measures for chronic and experimental pain. *Pain* 17(1): 45-56, 1983.
33. Pucci GC, Rech CR, Fermino RC, Reis RS. Association between physical activity and quality of life in adults. *Rev Saude Publica* 46(1): 166-179, 2012.

34. Rothschild B. Review: Evidence for the effectiveness of surgery for low back pain, radiculopathy, and spinal stenosis is limited. *Evid Based Med* 14(6): 180-181, 2009.
35. Simpson EL, Duenas A, Holmes MW, Papaioannou D, Chilcott J. Spinal cord stimulation for chronic pain of neuropathic or ischaemic origin: Systematic review and economic evaluation. *Health Technol Assess* 13(17): 1-154, 2009.
36. Strohle A. Physical activity, exercise, depression, and anxiety disorders. *J Neural Transm* 116(6): 777-784, 2009.
37. Thomson S, Jacques L. Demographic characteristics of patients with severe neuropathic pain secondary to failed back surgery syndrome. *Pain Pract* 9(3): 206-215, 2009.
38. Turner JA, Loeser JD, Deyo RA, Sanders SB. Spinal cord stimulation for patients with failed back surgery syndrome or complex regional pain syndrome: A systematic review of effectiveness and complications. *Pain* 108(1-2): 137-147, 2004.
39. Vanhelst J, Fardy PS, Duhamel A, Beghin L. How many days of accelerometer monitoring predict weekly physical activity behaviour in obese youth? *Clin Physiol Funct Imaging* 34(5): 384-388, 2014.
40. Wong AY, Karppinen J, Samartzis D. Low back pain in older adults: Risk factors, management options and future directions. *Scoliosis Spinal Disord* 12: 14, 2017.
41. Zhang YG, Guo TM, Guo X, Wu SX. Clinical diagnosis for discogenic low back pain. *Int J Biol Sci* 5(7): 647-658, 2009.

