



## Effect of Epidural Pulsed Radiofrequency with Neuro-Stimulation in Management of Thoracic Spinal Cord Injury

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Submitted: 14 November 2022; Accepted: 18 December 2022; Published: 27 January 2023

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### ABSTRACT

**Background:** Patients with spinal cord injury suffering from functional disability and reduced quality of life, in addition to conventional managements, many spinal cord researches try to develop effective repair treatment which can restore sensory and motor function to near-normal values, one of these new strategies is the neuromodulation

**Objective:** we aim to show the effect of spinal cord stimulation with epidural radiofrequency on improvement of trunk stability, mobility, standing, postural control, and assisted walking which will increase performance in activities of daily living (ADLs) .

**Patients and Methods:** we randomized 37 of chronic thoracic (T4\_T10) spinal cord injuries of ASIA Impairment scale grade A(completes SCI) who are under conventional rehabilitation treatment to receive epidural pulsed radiofrequency and spinal cord stimulation and follow the improvement of sensory , motor function, trunk stability, assisted walk, and performance in activities of daily livings (ADLs) using ASIA impairment scale, modified functional reaching test, functional ambulation category scale and Barthel index respectively.

**Results:** there were improvements of sense-motor function, trunk stability, assisted walk, performance function and quality of life after one year of treatment.

**Conclusion:** epidural pulsed radiofrequency and spinal neuro-stimulation combined with the conventional rehabilitation treatment showed significant advantage in improvement of neural activity, performance independency and quality of life.

**Keywords:** *spinal cord injury, epidural pulsed radiofrequency, ASIA Impairment scale, modified functional reaching test, functional ambulatory category scale, Barthel index*

## INTRODUCTION

Spinal cord injury is a devastating neurological disorder that is associated with life-long neurological condition with motor, sensory, and autonomic deficits (1). Up to 90% of SCI cases are caused by trauma including vehicle crashes, sports injuries, falls or violence (2). The overall global incidence of traumatic spinal cord injury is 10.5 cases per 100,000 person, resulting in an estimated 768,473 new cases annually worldwide, traumatic SCI is one of the major source of morbidity and mortality throughout the world (3). Spinal cord injury (SCI) is a traumatic life-changing event that has a significant impact on the affected individual as well as the health system. This includes hospitalizations, frequent visits for rehabilitation and medical care and assistance with activities of daily living over a lifetime (4). In the USA, total cost for a hypothetical individual injured at age 25 was estimated to be between \$1 and \$3.5 million, \$0.85 to \$2.1 million if the individual is injured at 50 years of age depending on severity of injury (5).

Traumatic spinal cord injury can drastically disrupt mobility and change the way individuals interact with their surroundings, prompting adaptation to maximize the independence performance of activities of daily livings (ADLs). While in a seated position, impairment of trunk and leg muscles activation leads to an inability to maintain the position of the spine, pelvis, and hip when challenged against gravity. Thus individuals with SCI have a significantly diminished ability to reach forward, or laterally, from a seated position, as well as a reduced capability to perform movements that are depend upon motor control of the trunk and postural muscles(6). In addition to this SCI patient complain from many medical conditions like pain, spasticity, sexual dysfunction and fertility, pressure ulcer, thromboembolic disease, and renal problems.

The conventional management of SCI were created more than half of century ago by the pioneering work of Dr Donald Munro in the United State and by Sir Ludwig Guttmann in the United Kingdom which consist of specialized medical care and comprehensive rehabilitation focusing on securing good health and maximum

function in mobility and self-care compatible with the neurological condition (7), but in contrast to the advance in the care of SCI, decades of intense efforts by basic research scientists have achieved little clinically to reverse the neurological lose associated with SCI by protection or regenerated of axon within the injured spinal cord (8).

The creative use of microelectronic technological development in medicine may result in quicker development of new effective compensatory treatment to improve function after spinal cord injury than the search for a 'cure' through basic regeneration research involving varying types of stem cells because achieving a 'biological cure' for SCI will still require understanding of vast and yet to be discovered scientific knowledge and overcoming enormous scientific obstacles (7). One of these effective compensatory treatments is the neuromodulation by epidural pulsed radiofrequency and spinal stimulation.

### *Pathophysiology of Traumatic Spinal Cord Injury (9)*

The initial mechanical trauma to the spinal cord initiates a secondary injury cascade that is characterized in the acute phase (that is, 0–48 hours after injury) by edema, hemorrhage, ischemia, inflammatory cell infiltration, the release of cytotoxic products and cell death. This secondary injury leads to necrosis and/or apoptosis of neurons and glial cells, such as oligodendrocytes, which can lead to demyelination and the loss of neural circuits.

In the subacute phase (2–4 days after injury), further ischemia occurs owing to ongoing edema, vessel thrombosis and vasospasm. Persistent inflammatory cell infiltration causes further cell death, and cystic micro cavities form, as cells and the extracellular architecture of the cord are damaged. In addition, astrocytes proliferate and deposit extracellular matrix molecules into the perilesional area.

In the intermediate and chronic phases (2 weeks to 6 months), axons continue to degenerate and the astroglial scar matures to become a potent inhibitor of regeneration. Cystic cavities coalesce to further restrict axonal regrowth and cell migration (9).

### ***Neuromodulation for Spinal Cord Injury***

Applying electrical stimulation to modulate the function of the spinal cord began almost 60 years ago when spinal cord stimulation was first attempted for use in chronic pain in 1967(10). Cook (1976) noted incidentally that epidural spinal cord stimulation (eSCS) treated participants had improvement in motor function (11). Numerous animal studies demonstrated activation of central pattern generator (CPG) within the spinal cord for purpose of eliciting forced walking after spinal cord transection prompted investigation of the use eSCS for this purpose in humans (12). In 2011, Harkema et al., Reported the surprising finding that while eSCS may modulate CPG circuits, it also seemed to restore some supraspinal over lower extremity movement. This work demonstrates that eSCS could restore standing, stepping, and volitional movement in a subject three years out from a motor complete SCI (13). Post-mortem analysis of spinal cord in chronic SCI revealed a small but significant percentage of corticospinal tracts remaining intact despite motor and often sensory complete clinical grades (14). Later on many researcher all over the world report same results like Wagner et al., 2018 , Gill et al., 2018 , Grahn et al., 2017 , Angeli et al., 2018 and in Iraq Jubara 2021.

### ***Mechanism of Action of SCS***

The eSCS-mediated restoration of voluntary movement in patient with a clinically “complete” SCI is thought to be due to neuroplasticity changes within a surviving group of neurons, signify that complete SCI May not to be as common as thought(15). The exact mechanism of restoring functional recovery not fully understood, it is widely accepted that eSCS primarily activates afferent neurons in the dorsal roots (16). Proprioceptive afferents are essential in eSCS-induced recovery and their absence or inhibition in animal studies suppresses functional recovery. The sustained effect of eSCS points to

the monosynaptic pathway between the stimulated proprioceptive neurons and the corresponding agonist motor neurons. With repeated stimulation of this circuit, Hebbian plasticity is thought to strengthen synaptic connection and increase recruitment of motor neurons, which in turn augment the ability of surviving corticospinal neurons to facilitate volitional movement (17). While this proposed mechanism facilitates movement by forming orthodromic action potentials (APs) in the proprioceptive fibers that propagate toward the motor neuron, it must be noted that eSCS produce bidirectional APs. The antidromic APs travel toward the distal sensory organ and may collide with and subsequently interfere with endogenous proprioceptive signals, a phenomenon known as antidromic collision (16). The recruitment and plasticity of propriospinal neurons are also thought to play critical role in regeneration. Propriospinal neurons reside entirely within the spinal cord and project to one or more ipsilateral and/or contralateral locations, often transcending multiple spinal segments, they work in concert to facilitate rhythmic motor movement and are an essential component of locomotor central pattern generators (CPGs) (18).

### **PATIENTS AND METHODS**

This was a randomized clinical trial, conducted at AL-Arabi private Hospital from April 2021 to April 2022. Included 37 patients 25 male and 12 female (percent 67.6/32.4), age 16-54 years old (mean 31.81SD 11.150) with chronic (more than 6 months since injury), traumatic thoracic spinal cord injury (T4-T10). All the participant are ASIA impairment scale classification (A) and Ambulation category score (zero) who are under conventional medical and rehabilitation management of SCI. Sensory score, motor score of lower limb, modified reaching test, and Barthel index were collected before stimulation therapy. Clinical characteristics in table 1

**TABLE 1.** Clinical characteristics of the patients

Exclusion criteria:

| Clinical characteristics   | NO. | mean  | SD    | Min. | Max. |
|--|-----|-------|-------|------|------|
| Sensory score before stimulation /normal 112                                     | 37  | 63.68 | 12.48 | 44   | 86   |
| Motor score of lower limb before stimulation /normal 25                          | 37  | 0.11  | 0.65  | 0    | 4    |
| Modified functional reach <b>central</b> before stimulation /normal $\geq 25$ cm | 37  | 6.83  | 2.81  | 4.0  | 12.4 |
| Modified functional reach <b>left</b> before stimulation /normal $\geq 25$ cm    | 37  | 5.82  | 2.63  | 3.0  | 11.5 |
| Modified functional reach <b>right</b> before stimulation /normal $\geq 25$ cm   | 37  | 5.66  | 2.65  | 3.0  | 11.0 |
| Barhtel index before stimulation /normal 100                                     | 37  | 16.76 | 2.93  | 15   | 25   |

**Coagulopathy**

Medical problems like high blood pressure 200 mmHg or above

Psychiatric problems

Unhealed pressure ulcer

Patient asked to hold any drug used for spasticity or drugs affect coagulation before suitable period

**Procedures**

A written consent obtained for each patient. Patient history, clinical examination, and MRI reviewed before intervention. Under full a septic condition, in the operating room with monitoring of vital signs ( pulse rate, SPO2, and blood pressure), a cannula inserted , Midazolam 0.05mg/kg, prophylaxis antibiotic given after tested, patient in prone position the sacral hiatus identified by ultrasound (or fluoroscope in difficult case ), under local anesthesia infiltration by 3-5 ml 2% lidocaine Cosman introducer needle 18 gauge passed through sacral hiatus to reach epidural space Figure 1 then Cosman catheter 66 cm length, blunt end 2mm diameter introduced through the needle to passed to

anterior epidural space fluoroscopic guided to reach the targeted level Figure2, Hydro dissection and adhesolysis of fibrosis by normal saline maximum 30 ml. the stimulation started from affected level down to the sacral segments by the following steps :

From the affect segment and blow, for each level, 4 min. pulsed radio-frequency at temperature 39 C°, 45 voltage, 200 mAm, then 20 short burst of sensory stimulation according to response to maximum of 3 voltage and 5-10 min. motor stimulation with 5 Hz and 3 voltage. The stimulation time is 60 minute. We concentrate on the affected level and weak levels below specially T9, T12, L3, L5, and S1. After intervention patient stay at hospital 2 Hours then discharge after checking vital signs.

Patient followed up for any complication, advised to continue the usual rehabilitation management and reexamined every 2 months for sensory, motor, trunk stability and ambulation progress, if there was improvement stimulation done every 2-3 months .

**FIGURE 1:** epidural needle through sacral hiatus



**FIGURE 2:** epidural catheter

**Statistical analysis**

All data of 37 patients recorded in computerized database with statistical analysis utility. SPSS version 22 used for analysis, suitable statistical procedures and tests were used accordingly at level of significance  $\leq 0.05$ .

**RESULTS**

37 patients enrolled in this study 25 male and 12 female (percent 67.6/32.4), age 16-54 years old (mean 31.81 SD $\pm$ 11.15). All patients are of ASIA

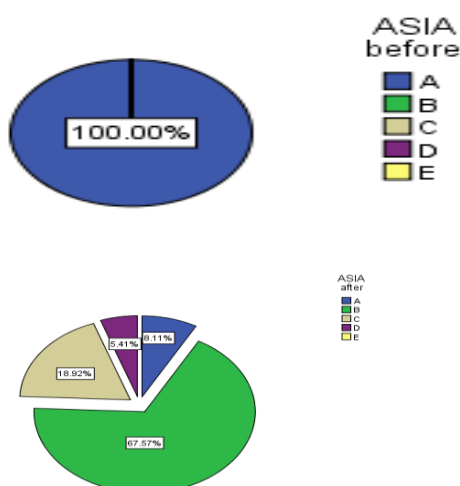
impairment scale classification A (complete spinal cord injury), duration of injury 6 months and more. Thoracic spinal cord injury level between T4-T10, all patients is on conventional medical care and rehabilitation management. The clinical characteristics mentioned in table 1. We use these criteria to compare before and after one year of epidural radiofrequency stimulation and results were as follow:

ASIA impairment scale

**TABLE 2:** ASIA scale before and after stimulation

| Classification     | A       | B         | C        | D       | E |
|--------------------|---------|-----------|----------|---------|---|
| Before stimulation | 37      | 0         | 0        | 0       | 0 |
| After stimulation  | 3(8.1%) | 25(67.6%) | 7(18.9%) | 2(5.4%) | 0 |

Compares between the impairment scale before and after stimulation using Wilcoxon Signed Ranks test show significant improvement (Z = -5.35, P. value < 0.001)



**FIGURE 3:** ASIA Scale changes after stimulation

**Sensory scoring using ASIA impairment scale**

The sensory grading from C2 to S5 on both sides of the body as 0= Absent, 1= Altered (either decreased sensation /impaired or hypersensitivity), 2= Normal taken for each level including light touch and pin prick, normal score is 112(19).

The mean score of the 37 patients before stimulation was 63.68±12.48 and became 80.97 ±10.78 after one year of treatment, using paired T-test to compare between sensory score before and after show significant improvement (P. value < 0.001).

Motor scoring of the lower limb (normal 25)

Consist of five levels:

L2 = Hip Flexors

L3 = Knee Extensors

L4 = Ankle Dorsiflexors

L5 = Long Toe Extensors

S1 = Ankle Plantarflexors

Muscle function grading

0 = Total paralysis

1 = Palpable or visible contraction

2 = Active movement, full range of motion (ROM) with gravity eliminated

3 = Active movement, full ROM against gravity

4 = Active movement, full ROM against gravity and moderate resistance in a muscle specific position

5 = (Normal) active movement, full ROM against gravity and full resistance in a functional muscle position expected from an otherwise unimpaired person (19).

The mean scoring of all the 37 patients before was 0.11±0.65 , and after one year of treatment became 4.22±4.82, comparing the two by Paired T-test show significant improvement (P. value < 0.001).

**Modified Functional Reaching Test**

It is a reliable tool for assessing sitting balance function in individuals with spinal cord injury. We use it to assess trunk stability, the test done in sitting position, it consists of three conditions over three trials

Sitting near the wall and leaning forward

Sitting with the back to the wall and leaning right

Sitting with the back to the wall leaning left (20).

The distance recorded in centimeters, normal value is ≥ 25cm. The results of the test before and after one year of treatment show significant improvement in trunk stability as in table 3

**TABLE 3:** Modified Functional Reaching Test before and after

| Test          | Before    | After      | P. value |
|---------------|-----------|------------|----------|
| Central reach | 6.83±2.81 | 24.55±2.86 | < 0.001  |
| Right reach   | 5.66±2.65 | 22.53±2.92 | < 0.001  |
| Left reach    | 5.82±2.63 | 22.55±2.84 | < 0.001  |

Paired T-test used in comparison

The interpretation of Modified Reaching Test (21)

≥ 25 cm normal or low risk of fall

15 – 25 cm risk of fall is 2X greater than normal

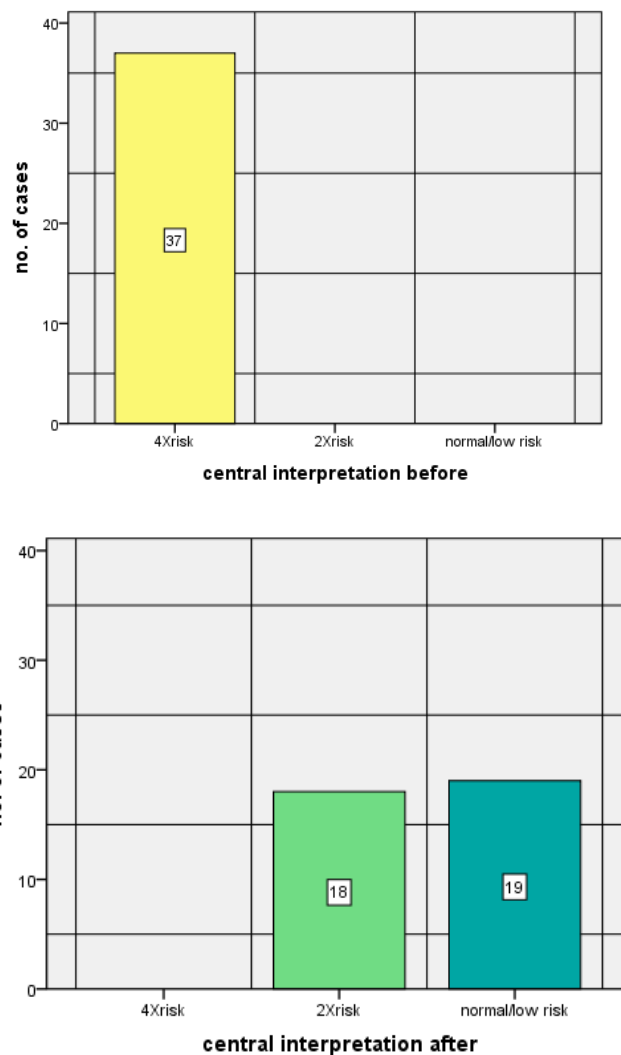
< 15 cm risk of fall is 4X greater than normal

Unwilling to reach risk of falling is 8X greater than normal.

Comparison between results of modified reaching test interpretation show significant improvement in trunk stability of the all patients after stimulation as in table 4 and figure 4, which in turn lead to improvement in performance dependence.

**TABLE 4:** Modified Reaching Test Interpretation before & after Stimulation

| Test interpretation    | Normal or low risk | Fall 2X grater | Fall 4X grater |
|------------------------|--------------------|----------------|----------------|
| C. reach inter. before | 0(0%)              | 0(0%)          | 37(100%)       |
| R. reach inter. before | 0(0%)              | 0(0%)          | 37(100%)       |
| L. reach inter. before | 0(0%)              | 0(0%)          | 37(100%)       |
| C. reach inter. after  | 19(51.4%)          | 18(48.6%)      | 0(0%)          |
| R. reach inter. after  | 15(40.5%)          | 22(59.5%)      | 0(0%)          |
| L. reach inter. after  | 16(43.2%)          | 21(56.8%)      | 0(0%)          |



**FIGURE 4 :**change in the trunk stability before and after stimulation

**Functional Ambulation Category**

Is 6 points functional walking test that evaluates ambulation ability, determining how much human support the patient requires when walking, regardless of whether or not they use a personal assistive device (22).

**Scoring and Score Interpretation (23)**

Score 0: Nonfunctional ambulatory  
 Score 1: Ambulator requires continuous manual contact support body weight as well as to maintain balance or to assist.

Score 2: Ambulator who requires intermittent or continuous light touch to assist balance or coordination.

Score 3: Ambulator, dependent on supervision, patient ambulates on level surface need standby person for safety or verbal cueing.

Score4: Ambulator, independent level surface only.

Sore 5: Ambulator, independent who can walk everywhere including stairs.

All the 37 patient before stimulation were nonfunctional ambulatories (score0), but after one year of treatment scoring changes as table 5

**TABLE 5:** change in scoring according Functional Ambulatory Category(FAC) before & after stimulation

|            | Score 0  | Score 1 | Score 2   | Score 3   | Score 4  | Score 5 |
|------------|----------|---------|-----------|-----------|----------|---------|
| FAC before | 37(100%) | 0       | 0         | 0         | 0        | 0       |
| FAC after  | 6(16.2%) | 1(2.7%) | 12(32.4%) | 13(35.1%) | 5(13.5%) | 0       |

Wilcoxon Ranks Test used  $Z = -4.94$ , P. value was  $<0.001$

Comparison of the scorings of patient, before and after, stimulation showed significant improvement of patient’s ability of walking.

**Barthel Scale / Index (BI)**

Is an ordinal scale used measure performance in activities of daily livings (ADLs), it is measure the degree of assistance required by an individual on 10 items of mobility and self-care (24), normal score is 100.

The mean Barthel index score of the 37 patient was  $16.76 \pm 2.93$  and became  $65.21 \pm 10.56$  after

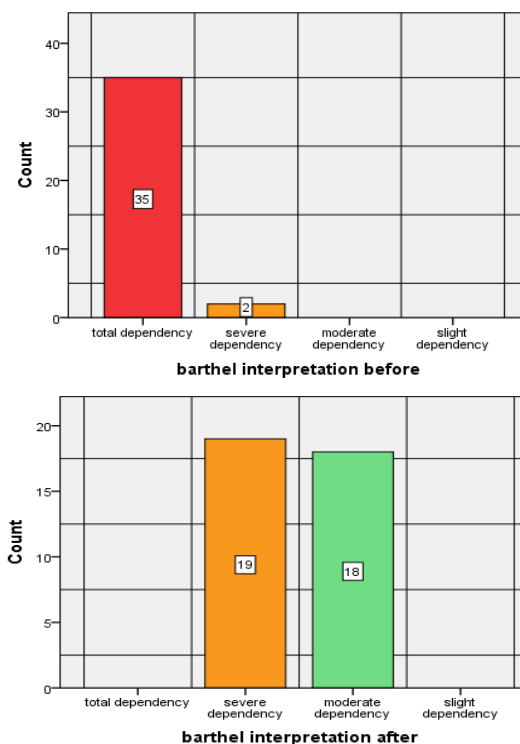
one year of treatment comparison between the two means using Paired T-test showed significant (P. value  $< 0.001$ ) improvement of the patients activities of daily livings and performance dependence .

Proposed guidelines for interpreting Barthel scores are that (25):

- Score 0 – 20 total dependency
- Score 21 – 60 severe dependency
- Score 61 – 90 moderate dependency
- Score 91 – 99 slight dependency

So distribution of patients score according these guidelines before and after stimulation will clarify the improvement of dependency

| Barthel Interpretation | Total dependency | Severe dependency | Moderate dependency | Slight dependency |
|------------------------|------------------|-------------------|---------------------|-------------------|
| before                 | 35(94.6%)        | 2(5.4%)           | 0                   | 0                 |
| after                  | 0                | 19(51.4%)         | 18(48.6%)           | 0                 |



**FIGURE 5:** comparison of Barthel index interpretation before and after stimulation



## DISCUSSION

Spinal cord injury (SCI) is devastating, debilitating, and life-altering neurological damage that is correlated with severe physical, mental, social, and vocational impacts on the individual, family members, and healthcare systems (26). In addition to the conventional management, many treatments have been developed trying to restore sensory and motor function of spinal cord one of these promising treatments is the epidural stimulation (27). Fifty years after the introduction of SCS, several technological changes have occurred, with the most relevant taking place over the past few years. As hardware and software continue to improve, the effectiveness of the treatment will increase and the range of complications decrease (28).

In this clinical trial cosman catheter used for epidural stimulation which originally designed to use in treatment of back pain this idea came to one of the authors ( Dr. Jubara) after he notice in previous study (Ghassan Faris Idan et al., 2022) improvement of sensory and motor function of patients complain from failed back surgery who treated by this method.

The trial used as adjuvant to the conventional rehabilitation of (37) patients complain from complete spinal cord injury. The session of stimulation done every 2 months and patients followed up for one year to assess their improvement according ASIA grade, sensory, motor, trunk stability, ambulation and performance in activity of daily living.

The conversion of 37 patients all ASIA grade A was 25(67.6%) patient convert to B, 7(18.9%) converted to C, and 2(5.4%) converted to D, this consider significant change compare to recovery occurs in patients without stimulation (29). The increase in mean sensory score after one year was 17.29 and in motor score of lower limb was only 4.11; both consider positive compare to natural recovery (30).

The sensory recovery of the thoracic levels, which happened gradually in caudal direction, indicate also the improvement in motor function of nerves come from thoracic levels which supply muscles responsible of trunk stability (31) leading to increase stability of trunk. The Modified Reaching Test used to examine

stability clarifies this very good improvement especially when compare to studies use exercise only to increase stability (31). Triolo, Ronald J et al. reach to similar results using a surgically implanted multichannel pulse generator and intramuscular stimulating electrodes to activate lumbar erector spinae, quadratus lumborum, and gluteus maximus muscles bilaterally (33).

Concerning walking all the 37 patient was unable to walk before stimulation but after one year many patients start assisted walking using the walkers, crutches, or long lower limb brace, depend on Functional Ambulation Category scoring and score interpretation (23), results were good as 6 patients remain un walkers score 0, 1 score 1, 12 score 2, 13 score 3, 5 score 4, and no patient reach to totally normal score 5, compare to studies used implanted spinal cord injury like Smith, Andrew C et al. in a study on 11 patients diagnosed as complete spinal injury reached to similar results(34). The improvement of trunk stability and assisted walking lead to increase in dependence performance in activity of daily livings, we used Barthel index score to compare the functional outcome before and after stimulation the mean score was  $16.76 \pm 2.93$  and became  $65.21 \pm 10.56$  after one year this transfer the 37 patients from total dependency to 19 patients of severe dependency and 18 patients moderate dependency which is better compare Gupta, A et al., Who follow the functional outcome of such patients after 2 years of rehabilitation only (35).

The epidural pulsed radiofrequency with spinal stimulation is economically accepted in many studies (36, 37), minimal invasive procedure if compared to implant type which need surgery and have more expected complication (38). Luckily no serious adverse effect reported in this trial study. The studies of using this method in spinal cord stimulation are unavailable; this study may be the first, so longer duration of follow up needed for assessment.

### *Clinical impressions*

Most of patients who had pain or spasticity report significant reduction in pain and acceptable improvement in spasticity and few male patients had variable degrees of improvement in sexual function.

## CONCLUSIONS

The epidural pulsed radiofrequency with neuro-stimulation is effective treatment to partially restore sensory and motor function of patients with spinal cord injury and this lead to improve trunk stability, assisted walking, performance dependence of activities of daily livings and improve quality of life. It can be used as trial to choose the right patients for surgical implanted type of stimulation. We suggest conducting further studies with large sample size and longer duration for more evaluation.

### Authors' contribution

Dr. M. Jubara suggested the idea of using this method and performed the intervention.

Dr. G.F.Idan Monitoring of the patient.

Dr. A. Alhaffo analyzed the data and wrote the manuscript. All authors read and approved the final manuscript.

### Ethical Clearance

Ethical clearance and approval of the study are ascertained by the authors. The Institutional Review of Arabic board Committee approved this study. All ethical issues and data collection were in accordance with the World Medical Association Declaration of Helsinki 2013 for ethical issues of researches involving humans, informed consent obtained from all patients. Data and privacy of patients were kept confidentially.

### Conflict of interest

Authors declared none.

### Funding

None, self-funded by the authors

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