Case report

Galvanic vestibular stimulation in a patient with paraparesis following spinal cord injury: case report

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ABSTRACT | INTRODUCTION: Spinal cord trauma is one of the main causes of disability in young adults. The loss of motor control components stems from the loss of continuity of the neural pathways underlying the spinal cord, of which we emphasize the corticospinal, vestibulospinal, and reticulospinal tracts. Galvanic vestibular stimulation (GVS) can stimulate projection and propriospinal circuits related to body weight support and mobility. **OBJECTIVE:** This study aimed to describe a case of a patient with a spinal cord injury, disability scale C, and paraparesis sequelae a year ago, who improved his posture and recovered his gait after therapeutic intervention with galvanic vestibular stimulation associated with vestibular rehabilitation and neurofunctional physiotherapy. **METHODS AND MATERIALS:** The assessments carried out were a clinical assessment, the Functional Independence Measure (FIM), American Spinal Injury Association (ASIA) scale, a computerized graphic postural assessment, and a posturographic assessment using the Sensory Organization and Functional Reach Tests. The patient underwent the Therapeutic Proof for dosimetry of GVS, and then ten rehabilitation sessions were held with GVS associated with neurofunctional physiotherapy and vestibular rehabilitation. **RESULTS:** The patient showed changes in each of the assessments in the post-intervention evaluation. The main finding was that the patient recovered walking with support (parallel bar or walker) in the 8th session. **CONCLUSION:** Galvanic vestibular stimulation is a novel and promising adjunct to body support and mobility regarding stimulating motor control.

KEYWORDS: Spinal Cord Injuries. Galvanic Vestibular Stimulation. Paraplegia. Case Report.

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1. Introduction

Spinal trauma is a debilitating condition that occurs after a traumatic injury that usually affects the bony part of the spine and the internal part of this compartment where the spinal cord is located[1,2]. The spinal cord is a structure belonging to the central nervous system and is responsible for encompassing structures that pass through the central nervous system, where the so-called propriospinal circuits can be found[3-5].

Injury to the spinal cord usually occurs at one of its levels and can happen in the cervical, thoracic, lumbar, sacral, and coccygeal parts[4]. The main neurological signs observed show a restriction of voluntary movement, loss of sensation, autonomic changes such as bladder disorders, and spinal automatism below the level of the lesion[4,5]. Lesions in animals, such as cats, present physiological differences in motor control. When placed on a treadmill, the animal can support its body, and once started on the treadmill, gait according to the external stimulus of the treadmill is achieved[5]. Humans cannot sustain their weight, so gait training for patients with spinal cord injuries, which is becoming more common, should be done in conjunction with a weight suspension system or exoskeleton[5-7].

The neural circuits of gait control require a complex activity characteristic of the sequence of muscle contractions, especially between the flexors and extensors of the lower limbs[5,6]. This characteristic brings us back to the Central Pattern Generator (CPG), a rhythmic circuit that connects neurons in the lumbar spinal cord and which is still a challenge for researchers as to how the sum of supra-segmental and propriospinal action potentials connect in the alpha motoneuron to affect the muscle contraction itself[8].

The vestibular system (vestibulospinal tracts) associated with the reticulospinal tracts can recruit the body support. This characteristic is complementary to the stimulus coming from the corticospinal system. It is also believed that supra-spinal connectivity in humans, represented by the vestibulospinal and corticospinal tracts, can activate the pool of neurons in the lumbosacral region[9,10].

Vestibular evoked muscle responses in persons with spinal cord injury can be recorded below the level of the injury. It depends on the vestibular stimulus (galvanic vestibular stimulation), head position, and the reference posture. This response has been measured in erectors spinae, soleus, and tibialis anterior depending on the referenced posture. The vestibular evoked response can also modify the corticospinal tract activation[11].

Non-invasive brain stimulation (NIBS), applied through magnetic or electrical stimuli to the motor cortex in patients with spinal cord injury, may positively affect motor control in these patients, particularly in terms of strength, spasticity, mobility, and balance. However, these outcomes have yet to be supported by low evidence in this treatment[12].

2. Methods

The current study was carried out at the polyclinic of the Universidade Metodista de São Paulo (UMESP). This study was approved by the Ethics Committee of the Universidade Metodista de São Paulo (UMESP) under CAAE number 67942323.3.0000.5508, and all research was performed following relevant guidelines/regulations by the Declaration of Helsinki. The patient agreed to participate by signing an Informed Consent Form (ICF) before the study began. This study was also registered as Universal Trial Number (UTN) U1111-1295-1127 / approval number in the Brazilian Registry of Clinical Trials (ReBEC) under number RBR-8w55n2g on 14-08-2023. This description of the case report followed the CARE Checklist.

The initial assessments were carried out using the Functional Independence Measure (FIM), the

American Spinal Injury Association (ASIA) Scales, a photographic assessment of reference posture and Clinical Posturography in the sitting posture using the Sensory Organization Test, and Functional Reach Test using the Wii Balance Board Force Platform, connected to a Windows computer using the BrainBlox program.

The photographic assessment of reference posture was analyzed using the computer program AutoCad to measure the ideal line of gravity and the relative line of gravity and the segmental line and its deviation. The processing steps initiate with the vectorization of the silhouette of the subject's body, the base of support (bench), and the styrofoam balls representing the anatomical bone processes. The image was scaled and orthogonalized, and the ideal gravity line was drawn. The relative gravity line was drawn for the end, and the deviation angle was measured.

The clinical posturography was executed using the Sensory Organization and Functional Reach tests. The subject was positioned on a bench on which a Wii Balance Board force platform was placed. The Wii Balance Board force platform has a data acquisition rate of 100 Hz. The sensory organization test was conducted with the patient's eyes open and closed on the fixed force platform. Then, these conditions were repeated by placing a cushion on top of the platform and having the patient sit on it. The Wii Balance Board force platform was connected to the Windows notebook through the BrainBlox software from the University of Colorado Boulder. The clinical posturography was analyzed using the Elipse Final V9 program from the Lucy Montoro Network, and the kinetic data from the sensory organization test were acquired. The Functional Reach Test was also performed with the subject in the reference posture in the seated position.

The Galvanic Vestibular Stimulation (GVS) therapeutic proof was then carried out to establish the dosimetry for treatment using posturography[13,14]. The chosen dose has a better effect on the subject's postural control, in this case, in the sitting position.

The Galvanic Vestibular Stimulation was delivered in a non-invasive brain stimulation (NIBS) device Tes NKL, through the random noise stimulation current type. The electrodes were 5x7 cm, positioned behind the ears, over the mastoid process, and fixed with an elastic band. The positive and negative poles alternate at equal times following the stochastic phenomenon. The impedance was below 10 ohms most of the time after the device was turned on. No adverse effect was observed at any time during the sessions.

Scales, assessments, and tests were carried out before and after ten sessions of GVS associated with vestibular rehabilitation and neurofunctional physiotherapy. The exercises included vestibular-ocular exercises (x1 and x2, 10 series of 10 repetitions each, in horizontal and vertical planes), reach exercises with the mirror in up, down and side-by-side directions (approximately 5 minutes), throwing the ball (approximately 5 minutes), and rhythmic exercises with the legs with help from the therapists (first changing feet in a step on the sitting position, after that in the orthostatic position and after that, when the patient recovered walk, inside the parallel barre, 30 steps 3 to 5 times in the parallel barre length). The patient isn't enrolled in any other therapy during the study.

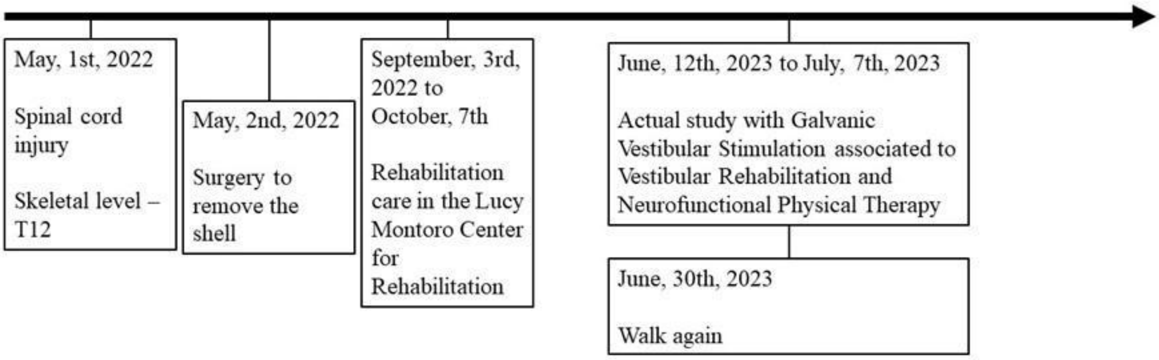
The sessions occurred three times a week and lasted between 1 hour and 1 hour and 20 minutes.

2.1 Case description

2.1.1 Diagnostic assessment, details on the therapeutic intervention, and outcomes

A 23-year-old male patient with sequelae of paraparesis following spinal cord trauma was recruited. The patient suffered a gunshot wound to the spinal cord, skeletal level T12, on May 1st, 2022 (Figure 1).

Figure 1. The sequence of events in the patient's clinical condition



Source: the authors (2023-2025).

The initial physical examination showed that the patient had stool control and was undergoing intermittent catheterization for urinary control. The lower right limb showed a limited passive range of motion in hip flexion due to a previous fracture caused by another projectile on the same occasion, and in the ankle due to the presence of *clonus* and elastic hypertonia in the triceps *surae* (limiting *calcaneus* to reach the floor in the sitting position). The patient showed preserved tendon reflexes in the upper limbs, increased reflexes in the distal region of the upper limbs, and elastic hypertonia in the bilateral biceps brachii (Ashworth Scale of 1). Muscle strength was grade 5 in the upper limbs. It decreased in the lower limbs (between 5 and 0), with a significant decrease in strength below the bilateral knee line (grade 1-0 muscle strength), with no voluntary movement in the ankle and foot segments.

The patient initially showed a neurological level of L2, according to the American Spinal Injury Association (standardized pre/post figures available from the ISNCSCI algorithm), Upper Extremity Motor Score (UEMS) of 50 and Lower Extremity Motor Score (LEMS) of 20. The ASIA impairment scale was not available because we couldn't perform anal examination. The patient was still unable to walk, and orthostatism was performed on a fixed bar in front of him. The Functional Independence Measure (FIM) assessment scored 94, requiring self-care, sphincter control, and mobility assistance (Figure 2).

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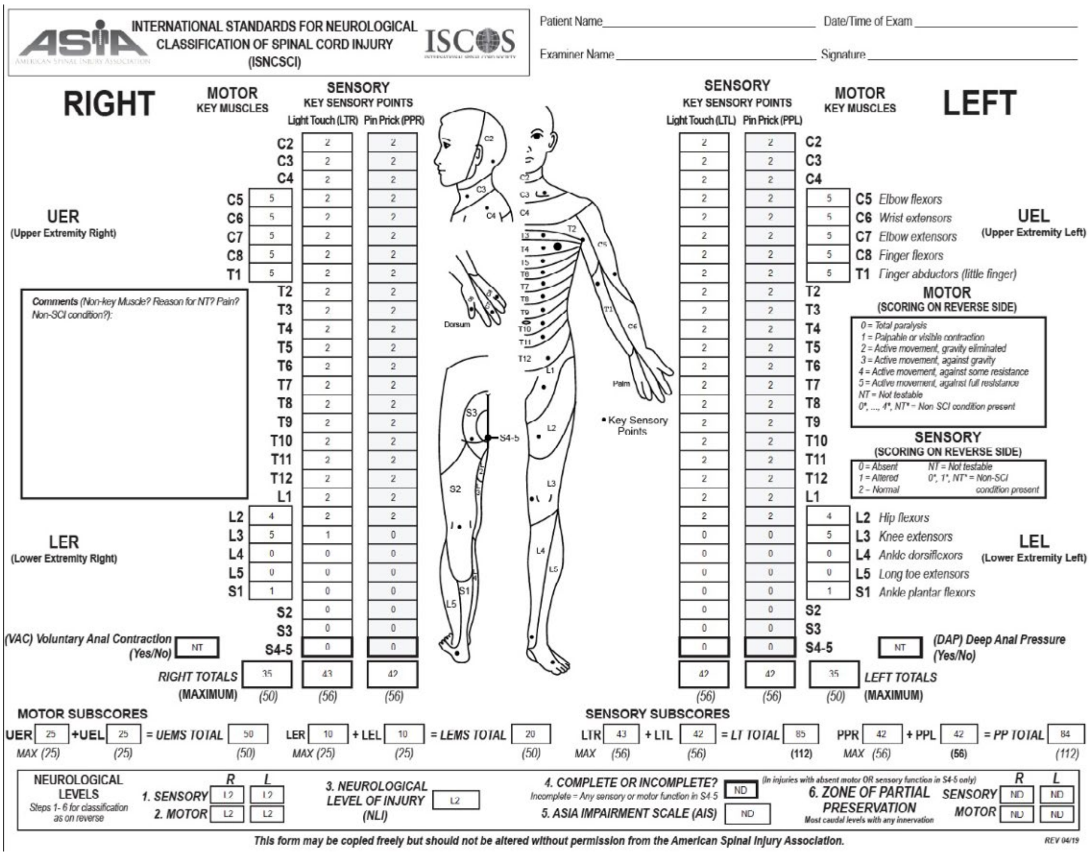
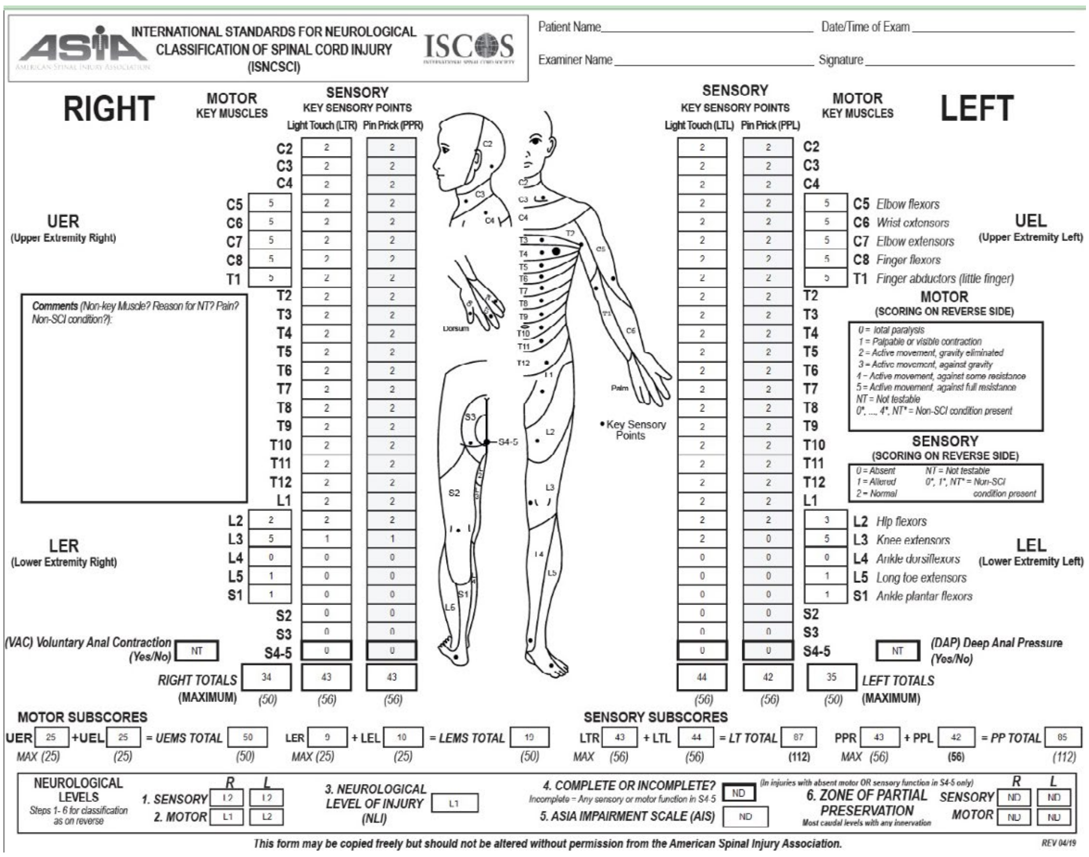
Figure 2. American Spinal Injury Association (ASIA) scales are used to assess the patient's condition before and after the intervention. The pre-intervention moment showed a neurological level of L2, according to the ASIA (standardized pre/post figures available from the ISNCSCI algorithm), Upper Extremity Motor Score (UEMS) of 50, and Lower Extremity Motor Score (LEMS) of 20. The ASIA impairment scale was not available because we couldn't perform an anal examination. In the post-intervention moment, the neurological level following ASIA was L1, UEMS maintained 50, and LEMS went to 19 (following ISNCSCI algorithm)

Pre-intervention



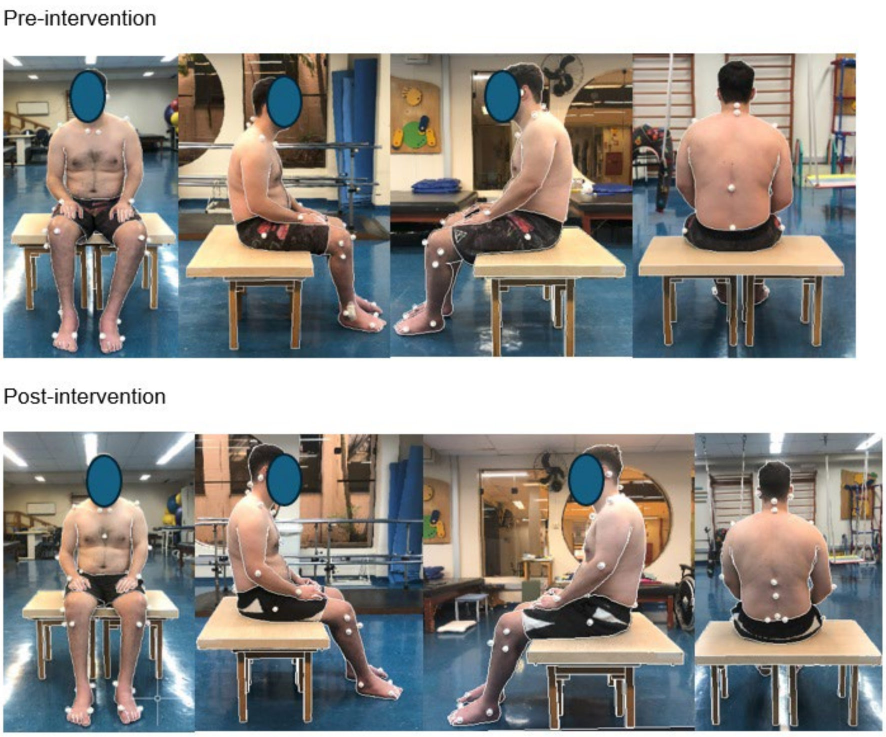
Post-intervention



Source: the authors (2025).

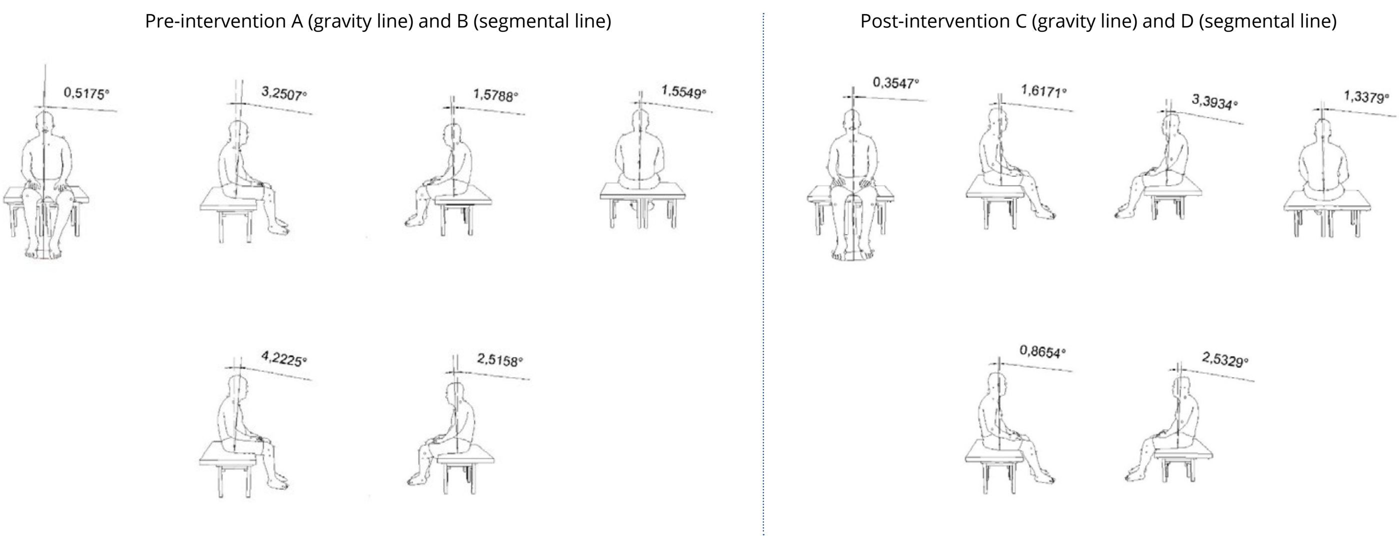
The computerized graphic postural assessment showed a deviation of the line of gravity (Figures 3 and 4). The initial postural assessment showed increased kyphosis of the spine (trunk flexion), abduction of the left lower limb, increased bilateral ankle angle, and bilateral head anteriorization (Figures 2 and 3). The photographs are shown in figure 3 with the vectorization made. Then, the gravity and segmental deviation also showed deviation (Figure 4).

Figure 3. Postural photography assessment in the anterior, right lateral, left lateral, and posterior views at pre (upper) and post-treatment (lower). The photographs were imported to AutoCad, vectorized, aligned, and scaled, and then the deviations to gravity and segmental line were made



Source: the authors (2023-2025).

Figure 4. Computerized graphic postural assessment showing the ideal gravity line (dashed) and the relative gravity line (solid) and marking the angle of deviation from this in the anterior, right lateral, left lateral, and posterior views at pre- (A) and post-treatment (C). The segmental line (great dashed) and its deviation are shown in the pre-treatment moment (B) and post-treatment moment (D) only in the lateral views



Source: the authors (2023-2025).

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The initial posturographic assessment was carried out using the sensory organization test and the functional reach test. The sensory evaluation showed less sway with visual sensory stimulation, more sway during the somatosensory condition, and the most sway for the vestibular condition (comparing the ellipse area of sway in the sensory conditions). Performance in the functional reach test showed 30 cm on the first attempt and 29 cm on the second for the displacement of the third finger forward (arms in 90° of flexion).

The therapeutic proof showed a clinical sign of eye vibration at 0.7 mA. The test on the force platform showed a signal with a smaller ellipse area compared to the other doses and a slightly increased speed compared to the others, so the 0.7 mA dose was chosen. The frequencies used were 1 and 100 Hz for the random noise variation.

The patient went on to physiotherapy sessions with galvanic vestibular stimulation (random noise), associated with customized vestibular rehabilitation and neurofunctional physiotherapy. The patient could stand with a walker in the sixth and seventh sessions. Session eight marked the first time he walked on a parallel bar on June 30th, 2023, after the traumatic event.

The FIM (score of 96 at the end) improved, and the neurological level following ASIA was L1, UEMS maintained 50, and LEMS went to 19 (following ISNCSCI algorithm). The post-treatment computerized graphic postural assessment showed a decrease in the relative line of gravity deviation and segmental line (Figure 2). The posturographic assessment showed a decrease in the sway of center of pressure in the fixed platform scores and an increase in the moveable platform scores in the sitting posture (Table 1), and it was possible to carry out an assessment with eyes open and a fixed platform in orthostatic with support at the end. The sensory evaluation showed swaying less with somatosensory stimulation, than visual and vestibular. Performance in the functional reach test showed 29 cm on the first attempt and 31 cm on the second for the displacement of the third finger forward (arms in 90° of flexion).

Table 1. Posturographic kinetic measures in the pre- and post-intervention moments. Sensory Organization Test (SOT) was performed sitting on a force platform (Wii Balance Board) on a wooden bench. The test is carried out in four conditions. Condition 1: eyes open, fixed platform (EO-FP); condition 2: eyes closed, fixed platform (EC-FP); condition 3: eyes open, moveable platform (EO-MP); condition 4: eyes closed, moveable platform (EC-MP). The functional reach (FR) test is also presented here in the pre- and post-intervention moments. Observe that in the post-intervention moment, there could be a measure in the eyes open, fixed platform in the orthostatic position with the support of the hands (EO-FP Ortho)

	Pre-treatment					Post-treatment					
	EO-FP	**EC-FP**	**EO-MP**	**EC-MP**	**FR**	**EO-FP 2**	**EC-FP 2**	**EO-MP 2**	**EC-FP 2**	**FR 2**	**EO-FP Ortho**
Total area (cm^2)	0.57	0.55	0.56	0.97	63.19	0.48	0.19	0.89	1	52.1	27.87
Sway (degrees)	88.6	81.31	162.7	122.49	74.62	73.49	105.17	70.07	83.43	103.78	147.48
Ellipse area (cm^2)	0.21	0.45	0.39	0.6	33.94	0.2	0.1	0.55	0.77	43.55	18.26
Length (cm)	40.73	40.75	40.63	42	58.87	43.44	43.11	44.09	42.45	74.73	159.12
Amplitude X (cm)	0.57	0.41	1.05	1	4.56	0.52	0.41	0.8	0.77	4.53	5.95
Amplitude Y (cm)	1	1.33	0.53	0.97	13.87	0.92	0.47	1.12	1.29	11.51	4.68
X RMS (cm)	1.24	1.4	0.83	0.98	6	0.32	0.75	3.9	3.48	1.17	9.64
Y RMS (cm)	4.34	4.68	3.26	3.04	5.21	2.08	1.79	0.95	1.19	9.25	0.99
Mean velocity (cm/s)	0.68	0.68	0.68	0.7	1.96	0.72	0.72	0.74	0.71	2.49	2.65
Velocity X (cm/s)	0.51	0.51	0.51	0.53	1.09	0.55	0.55	0.54	0.52	1.49	1.99
Velocity Y (cm/s)	0.35	0.35	0.35	0.35	1.4	0.36	0.36	0.39	0.38	1.63	1.35

Source: the authors (2023-2025).

The final physical examination showed an improvement in the passive range of movement of the ankles, especially on the right (the calcaneus was able to reach the floor in the sitting position). Elastic hypertonia was also observed in the upper and lower limbs, with no specific postural pattern (Ashworth Scale of 1). There was also the presence of finite clonus on the right and left ankles, maintenance of hyperreflexia in the upper limbs, arreflexia of the bilateral patellar and adductor reflexes, and aquileus reflex on the right present, and hyporeflexia of the aquileus reflex on the left.

The patient showed in the pre-intervention moment a Walking Index for Spinal Cord Injury (WISCI II) of 0 (representing "Client is unable to stand and/or participate in assisted walking"), and of 4 in the post-intervention moment (representing "ambulates in parallel bars, no braces and physical assistance of one person, 10 meters")[15].

No adverse signs were observed, and the patient was well-tolerating the intervention and exercises.

3. Discussion

The recovery of patients with sequelae after spinal trauma has been extensively researched in science today[1,7,16-19]. This study aimed to report on a case of a patient with sequelae after spinal cord injury and paraparesis sequelae a year ago, who recovered his gait (WISCI II from 0 to 4) after therapeutic intervention with galvanic vestibular stimulation associated with vestibular rehabilitation and neurofunctional physiotherapy. The aim of the study is interesting because it can add evidence for the therapeutic point of view and the effect on the patient's motor control.

The rehabilitation of patients with sequelae of spinal cord trauma is essential for their quality of life, their autonomy, and their resumption of an active life, and it has proved essential to recruit the residual neural networks involved in motor control[20]. However, the gains are still initial but promising. Jo & Perez[18] observed gains in rehabilitating patients with spinal cord injury sequelae using motor corticospinal neuronal stimulation associated with exercises. This therapy has been promising to minimize or reverse the sequelae in these patients.

Different surgeries involving the use of neural pacemakers and the placement of stem cells have been studied with promising results. Our previous study observed that the postural support function could be contemplated in a patient with spinal cord injury using galvanic vestibular stimulation[20]. Postural support has generally been advocated with the use of exoskeletons in patients with spinal cord injuries[7].

Galvanic vestibular stimulation is a promising resource in this context as it stimulates tracts such as the vestibulospinal tract and the reticulospinal tract that can promote weight support[20,21]. A motor feature related to vestibular stimulation and its function of guiding us about the force of gravity and head movement, performing two reflexes, the vestibular-ocular reflex and the vestibulospinal reflex. Those are important reflexes for the support function in postural control[9]. This was probably observed through computerized graphic postural assessment and clinical posturography in the sensory organization test, i.e.

The computerized graphic postural assessment showed a phenomenon about the deviation of the line of gravity passing through the body. This alignment can be compared with that of Pavlik et al.[22] has described the line between the mastoids and how galvanic vestibular stimulation reflects on the displacement of the center of pressure in the medial-lateral and anteroposterior axes. The authors described in greater depth that stochastic galvanic vestibular stimulation influenced the posture of healthy young people in their medial-lateral displacement.

The deviation from the segmental line supports the idea that the postural control responds to the coordinate integrated subsystems of egocentric, exocentric, and geocentric measures[6].

The present study observed a difference in the deviation of the axis of gravity in both the coronal and sagittal planes, differences in the segmental line, and the displacement of the center of pressure in posturographic measures. The phenomenon in the postural assessment possibly showed a rebalancing in how the body behaved about the line of gravity and the segmental line. Pavlik et al.[22] also describes how the position of the head can influence the variables observed in the postural and posturographic assessment, with the forward head position preferring orientations and stabilities in the coronal plane. Thus, we saw galvanic vestibular stimulation's influence on spatial and temporal variables.

Posturography also assessed a variation in the root mean square (RMS) variable. The ellipse area variable behaved like the RMS variable in x. In general, variations in speed in both x and y tended to increase in score. This is important since RMS is an important predictor of falls[23], and if it is lower, it may reflect stability. Combining the variables studied, we reinforce that galvanic vestibular stimulation influenced the deviation from gravity and the postural stability of this patient with sequelae of spinal cord trauma.

The use of galvanic vestibular stimulation to stimulate postural stability has been proposed in the literature[13,24-27] even in non-vestibular pathological patients. However, we stress that vestibulospinal and reticulospinal pathways must not have been injured at the time of the trauma since we obtained infra-lesional responses, even changing the motor neurological level in this patient.

For postural balance, sensory weighting must be considered between the somatosensory, visual, and vestibular systems. Somatosensory information was compromised in this patient, and this condition leads to sensory re-weighting, where the vestibular influence generated by galvanic vestibular stimulation is given greater weight for maintaining the function and the visual system[28]. One of the stimuli used during the sessions was vibratory stimulation of the soles of the patient's feet[29]. The somatosensory system of this patient appears to respond to the galvanic vestibular stimulation, possibly expressing the sensory integration of postural control.

The therapeutic proof revealed a beneficial stimulus at an intensity of 0.7 mA, lower than 1.0 mA, which primarily stimulates the hair cells of the vestibular system, strengthening a peripheral stimulus that stimulates the entire related neural pathway. The therapeutic proof was carried out using frequencies varying between 1 and 100 Hz, which can stimulate both the neck muscles (until 70 Hz) and posture (until 2 Hz) components[20,21]. However, more studies are needed to understand the clinical effects of galvanic vestibular stimulation in the hair cells and first neurons of the vestibular system; this is not a consensus in the literature yet[10].

The reticulospinal tract is also involved in anticipatory postural adjustment, an essential feature of postural control. It is reflected in step initiation and postural maintenance when moving the arms daily, for example, maintaining a sitting or standing posture[20,30]. Due to the gain in the acquisition of standing posture and walking with upper limb support, this finding reflects better stability limits and anticipatory postural adjustment.

The biggest finding in this study was that the patient could walk again (WISCI II from 0 to 4), although with support from the upper limbs (parallel bar equipment or a walker). This study clinically showed that galvanic vestibular stimulation was, in hypothesis, able to stimulate propriospinal circuits in the spinal cord, as proposed by Sayenko et al.[9]. This must be studied with more objective measures of the function of the central generator pattern in future studies.

We emphasize that the neural pattern of the vestibular system can be added to those of the corticospinal system in the activity of lower (alpha) motoneurons, which indicates that we may need to broaden the spectrum of stimulation of patients with spinal cord to achieve weight support, anticipatory postural adjustments and mobility.

We cannot discard that this patient could improve following conventional physiotherapy, due to this neurological level, which is described as having a walk prognosis, or natural progression, or even psychological motivation.

The main limitations of this study are that it is a case study with a single patient and proposes an individualized and customized therapy about the therapeutic proof. So, our results must be interpreted and generalized with caution, and more studies are needed. However, we would like to emphasize that this is a subsequent study using galvanic vestibular stimulation in a patient with a spinal cord injury with tetraplegia[20] which also showed beneficial results and can add to this some evidence.

This study evokes the possibility, in incomplete lesions, that the anterior part of the spinal cord, where vestibulospinal and reticulospinal tracts are located, can stimulate motor control of posture and mobility through vestibular stimulation, especially galvanic vestibular stimulation. The features of stimulation in alpha motor neurons after spinal cord injury must be tonically and phasically constituted to allow posture and movement in a dynamic system, as well as gamma motor neurons with the tonically static and dynamically adjusted motor control.

3.1 Patient perspective

The patient's final report was described by him as follows: "With the scientific study, I noticed improvements in postural control (trunk) when sitting and standing, I have more balance, more control in my knee (it no longer bends), a little strength in my thighs, and the long-awaited gait. I could walk on the parallel bar with the orthotics on both feet to give me more support. Extremely grateful!" (MAFS).

4. Final considerations

Galvanic vestibular stimulation is a novel and promising adjunct to body support and mobility, especially gait, stimulating the circuits of weight support, anticipatory postural adjustments and the rhythmic pattern of mobility/walking in patients with paraparesis following spinal cord trauma.

Data-availability statement

The data supporting this study's findings are not openly available due to reasons of sensitivity and are available from the corresponding author upon reasonable request. Data are located in controlled access data storage on a personal cloud drive.

Ethics statement

The current study was approved by the Ethics Committee of the Universidade Metodista de São Paulo (UMESP) under CAAE number 67942323.3.0000.5508, (Clinical Trials under no., UTN U1111-1295-1127; Brazilian Clinical Trials (Rebec) RBR-8w55n2g) on 14-08-2023. The patient signed the Informed Consent Form.

Authors' contributions

The authors declared that they have made substantial contributions to the work in terms of the conception or design of the research; the acquisition, analysis or interpretation of data for the work; and the writing or critical review for relevant intellectual content. All authors approved the final version to be published and agreed to take public responsibility for all aspects of the study.

Competing interests

No financial, legal, or political conflicts involving third parties (government, private companies, and foundations, etc.) were declared for any aspect of the submitted work (including but not limited to grants and funding, advisory board participation, study design, manuscript preparation, statistical analysis, etc.).

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