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The Role of Combined Vojta and Lokomat Therapy in Restoring Lower Limb Mobility and Muscle Strength in Patients With Spinal Cord Lesion

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Abstract: Spinal cord lesion (SCL) causes severe long-term motor and sensory deficits. Robotic-assisted gait training (Lokomat) and Vojta therapy are established neurorehabilitation approaches, but evidence regarding their combined use is limited. This retrospective study evaluates the effects of combining Vojta therapy with Lokomat robotic gait training on motor recovery, functional independence, and lower limb biomechanics in patients with traumatic and non-traumatic SCL. A total of 114 patients (aged 21-79 years) with paraplegia or tetraplegia treated at the Clinical Rehabilitation Hospital Băile Felix were included. Patients were assigned to two groups: L group − conventional physiotherapy and Lokomat training (n=50); V+L group − conventional physiotherapy, Lokomat, and Vojta therapy (VT), n=64. Functional assessment included the American Spinal Injury Association (ASIA) motor and sensory scores, Barthel Index, and Loko-mat parameters − Lokomat-Assessed Range of Motion (L-ROM), Lokomat-Assessed Force (L-Force), walking speed change, distance change, session duration change, and body weight sup-port (BWS) change. Statistical analysis was performed using JASP software, version 0.18.0, with a significance threshold set at 0.05. For data comparison, Student's t-test, chi-square test, and Mann-Whitney U test were applied. The combined Vojta–Lokomat group demonstrated signifi-cantly greater improvements in FIM scores, gait speed, walking distance, L-ROM, and L-Force compared with Lokomat alone. Median BWS decreased significantly in the combined group (p = 0.001), indicating improved active load-bearing capacity. No significant baseline differences were found between groups in age, sex, or neurological level. The integration of Vojta therapy with robotic gait training may enhance neuromotor activation and functional recovery in SCL, supporting its potential role as an effective multimodal rehabilitation strategy, and its clinical use to enhance load-bearing capacity, accelerate gait recovery, and optimize individualized re-habilitation strategies in patients with SCL.

Keywords: Spinal cord lesion, Vojta therapy, Lokomat robotic gait training, L-ROM, L-Force, Speed, Distance

1. Introduction

Medullary lesions represent a major public health problem with severe consequences for the mobility, autonomy, and quality of life of affected individuals. Functional recovery following spinal cord lesion (SCL) is a complex process that requires integrated approaches targeting both the restoration of locomotor function and the stimulation of neuronal plasticity [1]. Although several rehabilitation strategies have demonstrated benefits, evidence regarding the combined use of neuromotor facilitation techniques with robotic gait training remains limited, highlighting an important gap in current neurorehabilitation research. Robotic-assisted gait training (RAGT), among which Lokomat is the most widely used system, has emerged in recent years as a modern method of rehabilitation [2].

The Lokomat system enables intensive and standardized repetition of gait cycles, with adjustable parameters such as Body Weight Support (BWS), Guidance Force, walking speed, and distance covered. At the same time, it provides objective biomechanical data through integrated assessments such as Lokomat-Assessed Range of Motion (L-ROM) and Lokomat-Assessed Force (L-Force). [3, 4]. Clinical studies and meta-analyses have shown that robotic gait training using Lokomat can improve walking parameters − including speed, distance, and number of steps − as well as endurance capacity in patients with incomplete medullary lesions. However, clinical responses remain variable, particularly in relation to gait symmetry, postural control, and spasticity reduction [5-7].

The use of Lokomat in SCL rehabilitation offers several key advantages:

- Guided motion − The Lokomat robot applies motorized torques at the hip and knee joints, imposing a cyclic flexion–extension pattern similar to physiological gait;
- Parametric control − The therapist can adjust amplitude L-ROM, speed, and guidance force, allowing adaptation of the hip and knee trajectory to the degree of neurological impairment;
- Partial BWS − This reduces mechanical load on the pelvis and lower limbs, facilitating repetitive movement even in patients with low muscle strength;
- Corrective feedback − The system continuously measures trajectory errors and interaction forces (L-Force), reflecting in real time the degree of the patient's active participation versus passive robotic control [8, 9].

Vojta therapy (VT), also known as reflex locomotion, activates fundamental motor patterns through the stimulation of specific reflex zones, generating global muscular responses across the trunk and limbs. From a neurophysiological perspective, VT is thought to facilitate spinal central pattern generators (CPGs), enhance supraspinal–spinal connectivity, and promote sensorimotor integration through repetitive afferent stimulation. This activation recruits deep postural musculature and synergistic muscle chains, modulates muscle tone, and improves trunk stabilization—elements that are essential for efficient gait execution. By increasing neuromotor excitability and optimizing postural readiness prior to task-specific training, VT may function as a "pre-gait priming" intervention, potentially enhancing cortical and subcortical responsiveness to subsequent robotic-assisted gait training.In SCL, this therapy serves as a form of neuromotor facilitation, contributing to the improvement of trunk stability, regulation of muscle tone, and activation of neural networks involved in motor control. Due to its reflex-based nature and its ability to recruit synergistic muscle chains, VT can prepare the nervous system for task-specific motor training [10].

While both Lokomat training and Vojta therapy have demonstrated individual therapeutic benefits, there is limited evidence regarding their combined application. VT provides neuromotor priming and activation of postural musculature, while Lokomat delivers repetitive, intensive, and task-specific gait stimulation. The integration of these two complementary methods could potentially lead to measurable improvements in the objective parameters recorded by Lokomat- such as L-ROM, L-Force, walking speed, and distance covered, and to more efficient global functional capacity [9], so the rationale for this study was to explore whether the addition of pregait VT may influence Lokomat-related biomechanical parameters, thereby potentially modifying gait kinematics and movement efficiency during robot-assisted walking in patients with SCL.

The present article aims to analyze the neurophysiological and clinical foundations of the combined use of VT and Lokomat robotic training, to highlight their potential benefits on locomotor recovery in patients with spinal cord injury (SCI), and to emphasize the need for controlled clinical studies to validate this integrated rehabilitation approach.

2. Materials and Methods

2.1. Study Design

A retrospective observational study was conducted at the "Băile Felix Medical Rehabilitation Clinical Hospital", including patients admitted between February 2023 and February 2024 diagnosed with tetraplegia/tetraparesis or paraplegia/paraparesis resulting from SCL of either traumatic or non-traumatic etiology. All patients were evaluated at admission and at discharge using standardized clinical and functional assessment tools. The study received approval from the Local Ethics Committee of the Clinical Rehabilitation Hospital Băile Felix (Approval number: 2087/20.02.2024).

2.2. Inclusion/exclusion criteria

Inclusion criteria were as follows: patients with a confirmed diagnosis of SCL of either traumatic or non-traumatic etiology, presenting with tetraplegia/tetraparesis or paraplegia/paraparesis; age between 21 and 79 years; and a disease onset of at least one month prior to inclusion in the study. Exclusion criteria included: age below 21 or above 79 years; hemodynamic instability; unstable fractures; severe cognitive impairment; serious comorbidities contraindicating rehabilitation therapy; a history of autonomic dysreflexia; and patients in whom standardized assessments could not be performed.

2.3. Sample size

A statistical power analysis was conducted to ensure that the available sample size was adequate for detecting clinically meaningful differences between the two groups. A two-sided independent-samples t-test was assumed for comparing groups.

Based on previous studies involving robotic-assisted gait training in SCI, a moderate effect size (Cohen's d = 0.50) was expected. With a significance level of $\alpha = 0.05$ and a statistical power of 80% ($1 - \beta = 0.80$), the required sample size was estimated to be 51 participants per group (102 in total), using G*Power software (version 3.1.9.7, Heinrich-Heine University Düsseldorf, Germany).

In the present retrospective study, all eligible patients admitted during the study period were included. A total of 114 participants met the inclusion criteria: (n = 50) in the Lokomat (L) group and (n = 64) in the Vojta + Lokomat (V+L) group.

2.4. Patients enrolling

Of the 244 patients recruited, 114 met the inclusion criteria and were enrolled in the study. Based on the initial assessment at admission, which included determining the degree of neurological impairment using the American Spinal Injury Association (ASIA) Impairment Scale (AIS) as well as considering associated comorbidities and complications related to vertebro-medullary trauma, an individualized rehabilitation treatment plan was established for each participant. Patients were subsequently allocated into two groups: Group L − patients who underwent conventional rehabilitation therapy combined with robotic-assisted gait training using the Lokomat system; Group V+L − patients who received conventional rehabilitation therapy combined with Lokomat robotic gait training and VT (Figure 1).

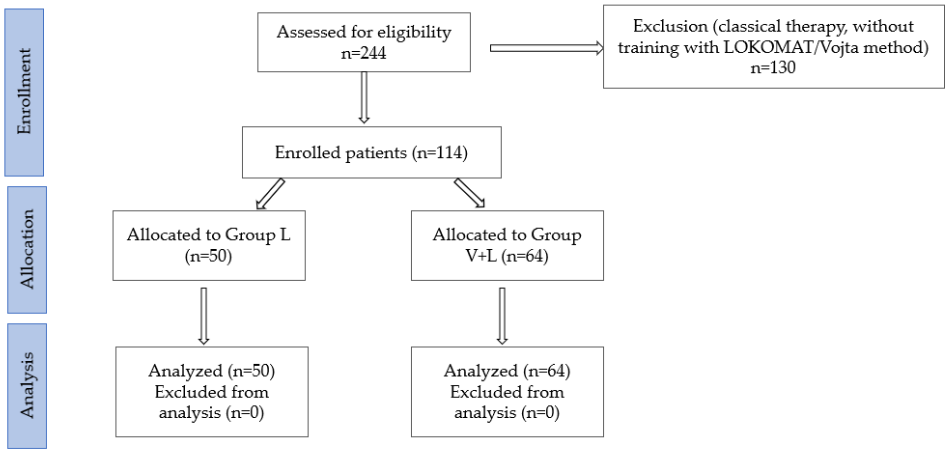

Figure 1. CONSORT flow diagram of the study.

For all study participants, the following data were collected: age, sex, etiology of SCI, traumatic or non-traumatic, time interval between injury onset and hospital admission (measured in months), environment of origin (urban or rural), neurological level of injury (assessed using the AIS scale), lesion type (complete or incomplete), classified according to the ASIA Scale (A, B, C, or D), and the ASIA motor and sensory scores at admission, and pharmacological therapy used by the participants, particulary any of the following medications: antispasmodics, gabapentinoids, opioids, antidepressants, **neurotrophic or neuromodulatory agents**. The level of autonomy in performing basic daily activities at both admission and discharge was evaluated using the Barthel Index, according to standard clinical protocols. Scores ranged from 0 to 100, with higher values indicating a greater degree of independence in performing activities of daily living (ADLs). Gait-related functional parameters were assessed using the Lokomat robotic gait training system software, which provides objective measures of performance, including: L-ROM, L-Force, walking speed, BWS, duration, and distance covered.

2.5. Study Tools

2.5.1. ASIA Scale

The ASIA neurological assessment scale constitutes the international reference standard for the systematic evaluation of patients with SCI. It includes a detailed examination of sensory function across 28 dermatomes − testing both light touch and pinprick modalities − and motor function in 10 key muscle groups on each side of the body. Based on these results, the clinician can identify the neurological level of injury and quantify the extent of neurological impairment. The neurological level corresponds to the lowest spinal segment showing normal motor and sensory function. A precise ASIA/ International Standards for Neurological Classification of SCI (ISNCSCI) examination is fundamental for accurate injury classification and reliable prognostic estimation [11, 12].

2.5.2. AIS Scale

The AIS grading system stratifies SCI into five categories (A-E), reflecting progressive degrees of preserved motor and sensory function, from complete loss of neurological function to normal examination findings. This standardized grading enables consistent comparisons of neurological status between individuals and over time, supporting both clinical monitoring and rehabilitation outcome evaluation (Table 1) [13].

Table 1. American Spinal Injury Association (ASIA) Impairment Scale (AIS) − classification of spinal cord injury (SCI).

AIS grade	Description
A	Complete injury − no motor or sensory function below the level of injury.
B	Incomplete injury − sensory function is preserved below the level of injury, but no motor function is present.
C	Incomplete injury − motor function is preserved below the level of injury, but the majority of key muscles have a strength grade < 3/5.
D	Incomplete injury − motor function is preserved below the level of injury, and the majority of key muscles have a strength grade ≥ 3/5.
E	Normal motor and sensory function.

2.5.3. The Barthel Index is a standardized clinical tool used to assess the degree of independence in performing basic activities of daily living (ADLs), such as feeding, dressing, personal hygiene, mobility, and stair climbing. The total score ranges from 0 to 100 points, with higher values indicating a greater level of autonomy [14].

2.5.4. The Lokomat® robotic gait training system (Hocoma AG, Switzerland) was used both as a therapeutic tool and as a quantitative assessment instrument for the evaluation of gait performance and lower limb function. The device integrates adjustable robotic orthoses for the hip and knee joints, a dynamic body-weight support system, and a treadmill, enabling standardized assessment of gait-related parameters. The integrated software automatically records the following variables: walking speed (km/h); body-weight support (kg), defined as the percentage of body mass unloaded during gait training, with lower values indicating improved load tolerance and postural control; walking distance (m), representing the total distance covered during each session and reflecting endurance and gait stability; and session duration (minutes). For walking speed, walking distance, and body-weight support, the average percentage change between the first and last training sessions was calculated automatically by the Lokomat system software for each participant. In addition, the Lokomat system provides objective biomechanical assessments, including assessments of passive L-ROM, which quantifies angular mobility at the hip and knee joints during the gait cycle and is expressed in degrees (°). Muscle strength was evaluated using L-Force, representing the isometric force of the hip and knee flexor and extensor muscle groups, measured in newton-meters (Nm) [15].

2.6. Rehabilitation treatment

All participants received a standard individualized rehabilitation program, including conventional kinesiotherapy and multidisciplinary supportive therapies. The conservative kinesiotherapy protocol was identical across groups and was delivered once daily, five days per week, for two weeks.

Patients in the L and V+L group underwent robot-assisted gait training using the Lokomat device (10 sessions over 2 weeks, 30 min/session). In the V+L group, VT was administered prior to each Lokomat session, once daily for 10 consecutive days, as a pre-gait priming intervention. All interventions were supervised by specialized physiotherapists.

VT was based on reflex locomotion and included two coordination patterns: reflex rolling and reflex crawling. Each technique began with a 1-minute resting phase, followed by firm, sustained, painless manual stimulation of specific trigger zones. After stimulation, the patient remained in the same position for an additional minute to allow reflex responses to persist.

Reflex rolling: *Supine:* head rotated ~30° toward the stimulation side; pressure applied in the thoracic region between the 7th–8th ribs; *Side-lying:* stimulation at the medial scapular border and anterior superior iliac spine.

Reflex crawling (prone): continuous stimulation at predefined zones, including the medial humeral epicondyle, acromion, thoracic region, medial scapular border, anterior superior iliac spine, medial femoral epicondyle, calcaneus, and gluteal region.

These stimulation patterns were intended to activate global muscular synergies, enhance trunk stabilization, and facilitate coordinated limb recruitment prior to robotic-assisted gait training. The intervention was standardized across al participants.

2.7. Pharmacological treatment

Concomitant pharmacological therapy included: **antispastic agents** (e.g., baclofen, tizanidine), **gabapentinoids** (gabapentin, pregabalin), **opioid analgesics (**e.g., **Doreta**, Skudexa), **antidepressants** (particularly serotonin/norepinephrine reuptake inhibitors such as Duloxetine, or tricyclic antidepressants such as Amitriptiline), **neurotrophic or neuromodulatory agents(**e.g., **Vitamins B group, Actovegin)**; no participants received botulinum neurotoxin injections during the study period.

2.8. Study Hypotheses

We hypothesized that the integration of VT with Lokomat training (V+L group) would potentially lead to significantly greater improvements in motor recovery, functional independence, and lower limb biomechanics compared to Lokomat training alone (L group).

2.9. Statistical Analysis

Statistical analysis was performed using JASP software, version 0.18.0, with the level of statistical significance set at $p < 0.05$.

Data with normal distribution were represented as mean (± standard deviation (SD)), while data with a distribution other than normal were represented as median (interquartile range (IQR)). Categorical variables were compared by Chi-square test or Fisher's exact test. For categorical variables, expected cell frequencies were examined prior to analysis. The chi-square test was applied when all expected counts were ≥ 5; otherwise, Fisher's Exact Test was used. For chi-square analyses, the χ^2 statistic and p-values are reported.

Data normality and homogeneity of variances were assessed using the Shapiro–Wilk and Levene's tests, respectively. Since the assumptions for parametric tests were not met for most variables, non-parametric tests were applied when appropriate.

Depending on the distribution of the data and the homogeneity of the variance, comparisons were made using the Student t test or the Mann–Whitney U test. For variables with unequal variances, the Welch t-test was used, either at the cohort level or within study groups. Comparisons within groups were made using the Wilcoxon signed-rank test. A $p<0.05$ was considered statistically significant.

3. Results

3.1. Baseline characteristics

An analysis of the baseline characteristics shows that there were no significant differences between the two groups with respect to age, sex, or urban versus rural background ($p > 0.05$).

As shown in Table 2, approximately one-third of the participants (33 %) were female, and over half of the patients came from urban areas. A statistically significant difference was observed in the time since injury onset. The median duration since onset was longer in the L group [94 months (IQR 112.25)] compared with the V+L group [48 months (IQR 48)], and this difference reached statistical significance (p = 0.002). At the cohort level,

Table 2. Baseline characteristics.

Parameter		L Group	V+L Group	Total	χ^2/t/W	p-value
Gender	Female, N (%)	19 (38)	19 (30)	38 (33)	0.873	0.350*
Residence	Urban, N (%)	25 (50)	34 (53)	59 (52)	0.110	0.740*
Age (years)	Mean ± SD	48.46 ± 13.63	44.57 ± 13.65	46.28 ± 13.72	1.507	0.135
	Min	21.00	22.00	21.00		-
	Max	77.00	79.00	79.00		-
Onset (months)	Median (IQR)	94 (112.25)	48 (48)	51 (84)	2128.5	0.002**
	Min	6	12	6		-
	Max	387	234	387		-

N − number of participants; Group L− Lokomat group; Group V+L − Vojta therapy (VT)+Lokomat group; SD − standard deviation; p* − chi-squared test; p − t-test, p**− Mann-Whitney test; χ^2 − chi-squared statistic value; t – student´s t test statistic; W – Mann-Whitney non-parametric statistic value.

Regarding the etiology of the SCI, data presented in Table 3 indicate that traumatic causes accounted for more than 80% of the cases included in the study, with no significant difference between the two groups (p = 0.918). The presence of tetraparesis was observed in approximately 40% of patients, while the remaining participants presented with paraparesis, again with no significant difference between groups (p = 0.502). Regarding the neurological level of injury, cervical, thoracic, and lumbar lesions were comparably represented in both groups. Cervical injuries were present in 32.0% of patients in the L group and 35.9% in the V+L group, while thoracic and lumbar injuries showed similar distributions. No statistically significant differences were detected

Table 3. Distribution according to etiology, the neurological level of injury, AIS grade, and functional deficit.

Variable	Category	L Group N (%)	V+L Group N (%)	Total, N (%)	χ^2	p-value
Etiology	Traumatic	41 (82.0)	52 (81.3)	93 (81.57)	0.011	0.918
	Non-traumatic	9 (18.0)	12 (18.8)	21 (18.42)		
Neurological level	Cervical	16 (32.0)	23 (35.9)	39 (34.21)	0.198	0.906
	Thoracic	13 (26.0)	16 (25.0)	29 (25.43)		
	Lumbar	21 (42.0)	25 (39.1)	46 (40.35)		
AIS grade	A	7 (14.0)	16 (25.0)	23 (20.17)	2.839	0.417
	B	16 (32.0)	21 (32.8)	37 (32.45)		
	C	16 (32.0)	18 (28.1)	34 (29.82)		
	D	11 (22.0)	9 (14.1)	20 (17.54)		
Functional deficit	Tetraparesis	18 (36.0)	27 (42.2)	45 (39.47)	0.450	0.502
	Paraparesis	32 (64.0)	37 (57.8)	69 (60.52)		

N − number of patients; AIS − ASIA impairment scale; L − Lokomat group; V+L − VT and Lokomat group; p— chi-squared test; χ^2— chi-square value.

3.2. Pharmacological Treatment

As shown in Table 4, no statistically significant differences were observed between the groups regarding the use of anticonvulsants, antidepressants, muscle relaxants, or opioids ($p > 0.05$). In contrast, statistically significant differences were identified in the administration of B-group vitamins and neuroprotective agents ($p < 0.05$).

Table 4. Distribution of pharmacological treatment across study groups.

Group	Gabapentin / Pregabalin	p-value	Baclofen / Tizanidin	p-value	Antidepressants (Duloxetine/ Amitriptiline)	p-value
L, N (%)	16 (32.00)	0.467	2 (4.00)	0.463*	3 (6.00)	1.000*
V+L, N (%)	24 (37.52)		6 (9.40)		4 (6.25)	
Total, N (%)	40 (35.08)		8 (7.01)		7 (6.14)	
Group	**Opioids**	**p-value**	**B-group vitamins**	**p-value**	**Neuroprotector (Actovegin)**	**p-value**
L, N (%)	2 (4.00)	0.463	33 (66.00)	0.039	1 (2.00)	<0.001*
V+L, N (%)	6 (9.40)		53 (82.81)		15 (23.45)	
Total, N (%)	8 (7.01)		86 (75.44)		16 (14.04)	

N–number of patients; p-value – chi-square test; p* – Fisher's exact test.

3.3. ASIA motor and sensory scores

The analysis showed no statistically significant differences between the groups at admission (Table 5). For the ASIA motor score, the L group had a median value of 65, indicating a relatively higher baseline motor performance compared with the V+L group, which showed a median of 55. Across all patients, the mean ASIA motor score was 59.9; however, the differences between the two groups did not reach statistical significance ($p = 0.070$). Regarding the ASIA sensory score, the L group presented a median of 74.5, slightly higher than that of the V+L group, which had a median of 69.5. The overall mean sensory score was 72.58, and no statistically significant differences were observed between the groups ($p = 0.143$).

Table 5. Mean values of ASIA motor and sensory scores.

Parameter	Group	N	Median (IQR)	p-value	Min	Max
ASIA motor score	L	50	65.00 (25.00)	0.070	35.00	90.00
	V+L	64	55.00 (20.00)		18.00	97.00
	total	114	-	-	18.00	97.00
ASIA sensory score	L	50	74.50 (33.75)	0.143	36.00	110.00
	V+L	64	69.50 (29.00)		20.00	110.00
	total	114	-	-	20.00	110.00

ASIA – American Spinal Injury Association; L – Lokomat group; V+L – VT and Lokomat group; IQR – interquartile ranges; p-value – Mann-Whitney U test.

3.4. Evaluation of Hip and Knee Joint Mobility

Overall, the L group presented slightly higher mean values for certain measurements – such as hip flexion range of motion (ROM) measured in degrees, and knee flexion- compared with the V+L group (Table 6). The median values and IQR indicate a large dispersion, but the distributions are similar between groups. Analysis of median values shows that for all hip and knee flexion and extension measurements, the values are close between groups, for example, the medians for right hip flexion being 15° in the L group and 16° in the V+L group, with IQRs of 14° and 19.25°, respectively. All analyzed variables showed p-values greater than 0.05, indicating that there were no statistically significant differences between the two groups for these joint mobility measurements.

Table 6. Mean values of hip and knee joint mobility.

L-ROM (°)	Group	Median (IQR)	p-value	Min	Max
Hip flexion right	L	15.00 (14.00)	0.618	0.000	45.000
	V+L	16.00 (19.25)		0.000	45.000
Hip extension right	L	3.50 (6.00)	0.148	0.000	20.000
	V+L	0.00 (5.00)		0.000	16.000
Hip flexion left	L	16.00 (14.00)	0.710	0.000	46.000
	V+L	16.00 (17.50)		0.000	47.000
Hip extension left	L	0.00 (4.00)	0.443	0.000	16.000
	V+L	0.00 (4.00)		0.000	18.000
Knee flexion right	L	18.00 (23.50)	0.232	0.000	86.000
	V+L	15.00 (25.75)		0.000	85.000
Knee extension right	L	0.00 (2.00)	0.497	0.000	13.000
	V+L	0.00 (2.25)		0.000	15.000
Knee flexion left	L	15.50 (21.00)	0.613	0.000	85.000
	V+L	16.00 (22.25)		0.000	85.000
Knee extension left	L	0.00 (1.75)	0.716	0.000	10.000
	V+L	0.00 (2.00)		0.000	10.000

p-value Mann-Whitney U test

3.5. Evaluation of muscle strength

Analysis of median values and IQR suggests that flexion force values are higher for the right hip in the V+L group and for the left hip in the L group, with a variable degree of dispersion. Extension forces are higher in the L group for both hips. Regarding the knee joint, median flexion forces were similar between groups on the right side (2.00 Nm in both groups), while slightly higher values were observed in the L group on the left side (2.00 Nm vs. 1.55 Nm). Median knee extension forces showed small between-group differences, with slightly higher values in the V+L group on the right side (1.80 Nm vs. 1.10 Nm) and comparable values on the left side.

Analysis of the obtained results revealed no statistically significant differences between the two groups in terms of muscle strength of the hip and knee flexors and extensors.

Table 7. The mean muscle strength values of the hip and knee flexors and extensors muscles, as determined using the Lokomat robotic assessment system.

L-Force (Nm)	Group	Median	IQR	p-value	Min	Max
Hip flexion right	L	6.00	22.87	0.643	0.50	100.00
	V+L	8.55	26.30		0.00	75.00
Hip extension right	L	3.00	8.75	0.155	0.00	80.00
	V+L	1.05	9.80		0.00	75.00
Hip flexion left	L	8.50	21.30	0.259	0.00	85.00
	V+L	5.60	23.55		0.00	70.00
Hip extension left	L	2.00	4.00	0.060	0.00	50.00
	V+L	1.00	5.40		0.00	69.00
Knee flexion right	L	2.00	8.47	0.710	0.00	68.00
	V+L	2.00	12.05		0.00	74.00
Knee extension right	L	1.10	5.80	0.757	0.00	62.00
	V+L	1.80	7.57		0.00	47.00
Knee flexion left	L	2.00	7.25	0.233*	0.00	68.00
	V+L	1.55	8.97		0.00	70.00
Knee extension left	L	1.00	9.30	0.718*	0.00	78.00
	V+L	1.10	4.80		0.00	55.00

p-value – Mann-Whitney U test; p*-value – Welch test.

3.6. Evaluation of Barthel Index scores at admission and discharge by study group and at cohort level.

Barthel Index scores at admission and discharge are presented by study groups and at the cohort level in Table 8. **Sample sizes (N) were identical at both time points,** as the same participants were assessed at admission and discharge. Within-group analysis demonstrated statistically significant differences between admission and discharge scores in both the L group and the V+L group, as well as across the total cohort, as assessed using the Wilcoxon signed-rank test. In the L group, the median was 40 at both admission and discharge, with interquartile ranges of 30.0 and 28.75, respectively. Despite unchanged median values, the within-group comparison revealed a statistically significant difference between the two time points ($p = 0.037$). In the V+L group, the median Barthel Index score at admission was 35, while the discharge assessment showed a median value of 42.5, and an interquartile range of 31.25 at both time points. The within-group comparison indicated a statistically significant difference between admission and discharge scores ($p < 0.001$). At the cohort level, median Barthel Index scores were 40 at both admission and discharge, with interquartile ranges of 30.0 and 32.5, respectively. The test demonstrated a statistically significant difference between admission and discharge values for the overall cohort ($p < 0.001$). Minimum and maximum values were comparable across groups and time points, indicating similar score ranges throughout the study period.

Table 8. Barthel Index scores at admission and discharge by study group and at the cohort level

Group	Barthel Index time point	N	Median (IQR)	Min	Max	p-value
L	Admission	50	40 (30.00)	5	85	0.037
	Discharge	50	40 (28.75)	5	85	
V+L	Admission	64	35 (31.25)	0	85	<0.001
	Discharge	64	42.5 (31.25)	5	85	
Total	Admission	114	40 (30.00)	0	85	<0.001
	Discharge	114	40 (32.50)	5	85	

N − number of patients; p-value − Wilcoxon signed-rank test.

3.7. Evolution of training speed, load, distance, and session duration

Percentage change in training-related parameters between the first and last assessment provided by the Lokomat software was used for statistical analysis. Walking speed demonstrated a normal distribution ($p > 0.05$), while body-weight support, walking distance, and session duration showed non-normal distributions ($p < 0.05$). Statistically significant differences were found between groups for all variables (Table 9). The L group tended to show a decrease in walking speed, while the V+L group showed improvement. For walking speed, the L group showed a negative change, whereas the V+L group demonstrated a positive change. The between-group comparison indicated a statistically significant difference ($p < 0.001$).

The analysis of medians and interquartile ranges (IQR) for BWS revealed a median value of 0.145 in the L group, indicating a slight increase or stabilization, with moderate dispersion (IQR = 0.295). In contrast, the V+L group showed a median value of −0.100, reflecting a reduction close to zero, with a comparable dispersion (IQR = 0.333). The statistically significant difference between groups ($p = 0.001$) indicates a greater reduction in BWS in the V+L group compared with Lokomat alone. Regarding walking distance, the median value in the L group (−0.065) suggests a slight decrease, whereas the median in the V+L group (0.220) indicates an increase in distance covered. The corresponding IQR values point to substantial variability within both groups. Concerning training session duration, a similar degree of dispersion was observed in both groups; however, an increase in session duration was more pronounced in the V+L group (median 0.160) compared with the L group (median −0.060).

Table 9. Percentage change between the first and last robotic gait training session assessed by the Lokomat Software.

Parameter	Group	Median (IQR)	Mean	SD	SE	Coefficient of variation	p-value
Walking Speed change %	L	-	− 0.123	0.224	0.032	− 1.825	<0.001
	V+L	-	0.175	0.276	0.035	1.575	
Body weight support (BWS) change %	L	0.145 (0.295)	-	-	0.360	5.398	0.001*
	V+L	− 0.100 (0.333)	-	-	0.046	− 59.767	
Distance change %	L	− 0.065 (0.432)	-	-	0.080	6.578	0.001*
	V+L	0.220 (0.863)	-	-	0.100	1.713	
Duration change %	L	− 0.060 (0.393)	-	-	0.083	6.850	0.003*
	V+L	0.160 (0.400)	-	-	0.072	2.327	

p-value − t-test; p*-value − Mann-Whitney U test; L − Lokomat group; V+L − VT and Lokomat group; IQR – interquartile range; M − Mean; SD − Std. Deviation; SE − standard error; Walking Speed measured in km/h; BWS measured in kg; Distance measured in meters; Duration measured in minutes. Percentage change calculated as [(last session value – first session value) / first session value] × 100%.

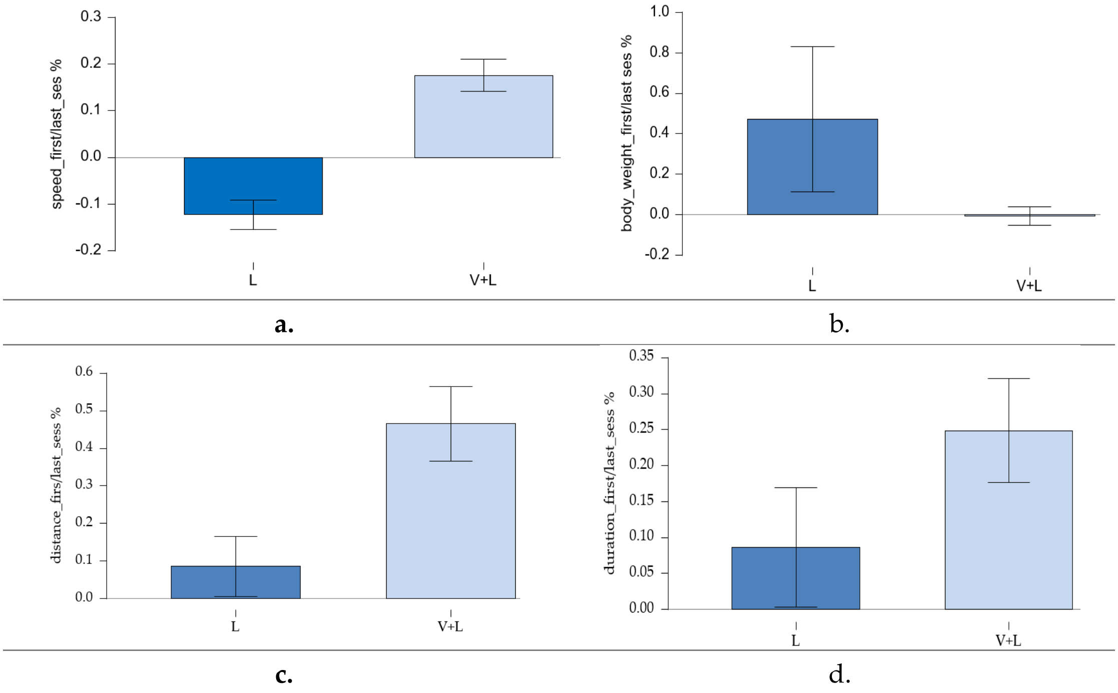

Figure 3. a. Mean walking speed at the first and last training session (%); b. Body weight support at the first and last session (%); c. Distance covered at the first and last session (%); d. Duration of the training session at the first and last session (%);

4. Discussion

The main objective of this study was to analyze in detail the clinical advantages of the integrated application of VT and Lokomat technology in neuromotor rehabilitation. The focus was to highlight how this combined approach can optimize therapeutic outcomes in patients with SCL by improving motor functions and accelerating the rehabilitation process. Furthermore, the article discusses the mechanisms through which these interventions can complement each other, as well as their potential to enhance the efficiency and individualization of treatment across different patient categories, thus contributing to the development of more effective and personalized rehabilitation strategies.

The analysis of baseline characteristics revealed no significant differences between groups regarding age, sex, or environment of origin, suggesting a homogeneous distribution of these demographic variables. Similar findings have been reported in previous studies, where these parameters did not significantly influence clinical outcomes in patients with SCL [16]. The sex distribution showed that approximately one-third of participants were female (33%), and more than half originated from urban areas. According to the literature, traumatic SCL is predominantly observed in male patients, as evidenced by most epidemiological studies [17]. In contrast, non-traumatic SCL tend to show a more balanced sex distribution, especially in older age groups, where vascular, tumoral, or degenerative etiologies become more prevalent [18].

Significant differences were, however, noted in the duration since the onset of injury, with the median duration since onset in the L group of 94 months compared with the V+L group where the median was 48 months. This may suggest that patients in the L group were in a more advanced chronic phase of the condition compared to those who also received VT in addition to conventional and robotic rehabilitation. The time since injury is a crucial parameter for assessing the potential for neurological and functional recovery, as chronic structural and physiological changes − such as muscle atrophy, intramuscular fat infiltration, secondary osteoporosis, and reduced neuronal plasticity, that can limit the effectiveness of rehabilitation [19, 20]. In chronic SCL, neuroplastic reorganization may become less efficient, and the response to robotic therapy progressively declines [21].

In the study Association Between Time-to-Rehabilitation and Outcomes Following Traumatic SCI, Herzer demonstrated that earlier rehabilitation onset is associated with higher levels of independence at discharge, findings supported by several other studies emphasizing the importance of early post-acute intervention [22, 23].

The analysis of etiology (Table 2) showed a predominance of traumatic causes, accounting for over 80% of cases, with no significant differences between groups ($p = 0.918$). This distribution aligns with international epidemiological data, which report higher rates of traumatic SCI, particularly among young men, due to road traffic, occupational, or sports-related accidents [24, 25].

Distribution by neurological level of injury (Table 3) indicated that cervical, thoracic, and lumbar injuries were similarly distributed between groups, with cervical lesions accounting for approximately one third of cases. No statistically significant differences were detected. This distribution reflects the heterogeneous nature of SCI populations typically encountered in rehabilitation settings and is consistent with previously reported epidemiological patterns for traumatic and post-traumatic SCL [26, 27]. A slight tendency toward higher-level (cervical) injuries was observed in the V+L group compared with the L group, which may have implications for rehabilitation and the response to robotic training. Cervical lesions are typically associated with more severe functional deficits, requiring more complex and multimodal rehabilitation programs [28]. According to the AIS classification, most patients were categorized as AIS grade B (32.45%), reflecting incomplete sensory–motor injuries, while fewer than 20% were classified as AIS grade D, characterized by partial preservation of motor function below the injury level.

From a therapeutic perspective, patients from the V+L group received more frequently B-group vitamin supplementation. This may be interpreted as a supportive therapeutic strategy aimed at enhancing neural function and promoting neuromuscular recovery, given the essential role of B vitamins in neuronal metabolism, myelin synthesis, and axonal regeneration. Experimental and clinical evidence suggests that vitamins B1 (thiamine), B6 (pyridoxine), and B12 (cobalamin) play a key role in maintaining peripheral and central nervous system integrity and may support recovery following neurological injury, including SCI [29]. Differences in concomitant pharmacological therapy, particularly the use of B-vitamins and Actovegin, were observed between groups and may have influenced neurological recovery. Although these medications were administered according to routine clinical practice and were not part of the experimental intervention, their potential confounding effect should be considered when interpreting the results.

In contrast, differences in the use of other medications, such as gabapentin/pregabalin and muscle relaxants, were not statistically significant. This finding suggests that pharmacological management of neuropathic pain and spasticity was applied in a comparable manner regardless of the rehabilitation modality used. Such results indicate a standardized therapeutic approach for pain and tone management in patients with SCI, while variations in vitamin supplementation may reflect protocol-specific strategies aimed at supporting neurological recovery alongside intensive rehabilitation interventions

The comparative analysis of percentage changes generated by the Lokomat system revealed statistically significant differences in all analyzed variables, suggesting that the distinct therapeutic approaches influenced locomotor outcomes differently. The L group showed a reduction in walking speed (-0.123) and a slight increase in weight load (+0.471%), indicating lower motor efficiency and reduced effort tolerance. Reductions in BWS requirements were more pronounced in the V+L group, indicating improved load-bearing capacity and enhanced active participation during gait training. This observation aligns with the hypothesis that neuromotor facilitation may improve trunk and proximal limb activation, thereby reducing reliance on external support during locomotion. Similarly, increases in walking distance and training session duration observed in the V+L group may reflect greater endurance, improved tolerance to training intensity, or enhanced motor control.

A notable finding was the divergent evolution of walking speed between groups. While the L group tended toward reduced walking speed over time, participants in the V+L group showed a more positive trajectory. The large effect size observed for the percentage change in walking speed underscores the potential clinical relevance of this difference and suggests that combined neuromotor priming and robotic training may better support motor adaptation.

The significant differences identified by the t-test ($p < 0.05$), and the Mann–Whitney *U* test confirm that the combined therapy had a greater impact on motor coordination and endurance, than robotic therapy alone. These effects may be explained by the activation of motor and postural reflexes induced by the Vojta method, which enhances motor unit recruitment and integration of proprioceptive feedback during robotic gait training [32-34]. Recent studies also show that incorporating reflex and sensorimotor stimulation into robotic rehabilitation programs can accelerate cortical reorganization and improve gait speed and locomotor stability [35-37]. However, despite these improvements in Lokomat-based parameters, no significant between-group differences were observed in the Barthel Index, indicating that gains in robotic gait performance did not translate into measurable differences in global functional independence improvements. The absence of significant between-group differences ~~in Barthel Index outcomes~~ suggests that the addition of VT to Lokomat-assisted gait training did not result in superior gains in global functional independence as measured by this scale, however the lack of intergroup difference in Barthel Index does not negate clinical relevance, but reflects scale sensitivity limitations. These findings suggest that, although both rehabilitation programs contributed to maintaining or improving independence, the addition of VT did not produce statistically significant differences in Barthel Index scores at discharge.

However, the maintenance of stable or slightly improved Barthel Index scores may reflect subtle improvements in postural control and motor coordination that are not fully captured by global functional scales [30, 31].

Comparable results were reported by Scivoletto et al., who found similar trends in Barthel Index evolution between admission and discharge, although most of their patients were classified as AIS grade A [31].

Our findings are consistent with these observations, indicating that the combination of reflex-based (Vojta) and robotic (Lokomat) gait training enhances neuro-muscular response and improves overall mobility outcomes in patients with incomplete SCL [38].

VT operates by eliciting reflex motor responses through tactile and proprioceptive stimulation in standardized postures, leading to coordinated trunk-limb activations and measurable cortical recruitment. The proposed mechanisms involve facilitation of brainstem networks, modulation of central pattern generators (CPG), and “priming” of residual sensorimotor pathways- all compatible with the goals of SCL rehabilitation, such as enhancing trunk stability, postural control, and respiratory function [10, 39].

Regarding gait recovery after incomplete SCL, current evidence supports task-specific robotic gait training (e.g., Lokomat) for improving walking distance, speed, and overall function, although results vary among studies and appear stronger in the subacute phase than in chronic stages. From this perspective, the role of VT may be best understood as a neuromotor priming intervention preceding gait training sessions, rather than as a substitute for them [40, 41].

Analysis of joint ROM for the hip and knee revealed comparable values between the two groups, with no clinically relevant differences. Overall, L group showed slightly higher mean values for certain joint mobility parameters, such as hip flexion ROM and knee flexion, compared with the V+L group. Median values and IQR indicated considerable dispersion; however, the distributions were comparable between groups. Analysis of medians and IQRs demonstrated that hip and knee flexion and extension values were similar across groups.

This homogeneity indicates that both groups started with essentially the same joint mobility and muscle strength, allowing us to attribute the observed functional differences more confidently to the type of intervention rather than to pre-existing biomechanical disparities. It is also important to emphasize that VT does not primarily target joint mobility, but rather aims to improve postural stability, trunk control, intersegmental coordination, and reflex locomotion patterns.

The analysis of hip and knee flexors and extensors muscle strength revealed no statistically significant differences between the L group and V+L group. Although minor tendencies were observed—such as higher hip flexion strength on the right side in the combined group and greater hip extension strength in the L group—these variations did not translate into meaningful between-group effects. The substantial variability observed across strength measurements suggests marked inter-individual differences in neuromuscular status, which may have limited the ability to detect subtle intervention-related effects.

Indeed, the literature indicates that VT does not aim to increase joint range through direct mobilization, but rather to activate reflex muscle synergies that promote optimal tone and intersegmental coordination [42, 43].

The stability of ROM values between groups supports the effectiveness of combining rehabilitation techniques, as patients were able to maintain or slightly improve passive and active mobility during robotic therapy. These results align with other studies reporting maintenance or improvement in joint mobility in SCL patients undergoing Lokomat-based gait training. Recent meta-analyses confirm that RAGT, particularly with Lokomat, significantly improves locomotor function in these patients [44].

Additionally, Lokomat has been shown to enhance gait symmetry and optimize gait biomechanics, outcomes that may also be influenced by individual factors such as body weight and degree of weight support [45]. Other systematic reviews focusing on SCI indicate that while Lokomat improves gait performance, its effects on spasticity are inconsistent, underscoring the need for more sensitive outcome measures than simple walking speed (e.g., 10-Metre Walking Test) [5, 46].

Recent multimodal approaches appear promising: meta-analyses suggest that RAGT combined with non-invasive brain stimulation (NIBS) may yield additional benefits- such as improved ASIA lower limb motor scores - although not all protocols (e.g., transcranial direct current stimulation – tDCS) consistently outperform placebo [47].

For subacute SCL, recent data show advantages over conventional physiotherapy regarding in gait performance, recommending prioritization of RAGT/Lokomat in AIS C patients, whereas some alternative gait training methods (e.g., Dynamic Parapodium Training - DPT) appear less effective for this subgroup [6, 48].

Moreover, therapist fatigue and high staffing requirements for manual body-weight-supported treadmill training (BWSTT) justify the use of automated systems such as Lokomat to increase training dose and consistency [41, 49, 50].

In non-traumatic SCL or spinal cord disease (e.g., degenerative myelopathy), studies using overground exoskeletons demonstrate feasibility and provide dosage guidelines, although optimal protocols and patient selection criteria remain to be established. Lokomat continues to represent the standardized treadmill-based robotic system with BWS, while mobile exoskeletons (e.g., Ekso) extend applications in incomplete SCL gait rehabilitation [51]. Overall, the results suggest the effectiveness of combining VT and Lokomat therapy in promoting motor improvement, supporting the need for further studies to confirm and optimize these interventions.

5. Strengths and limitations

This study has several notable strengths. First, it provides real-world clinical data derived from a retrospective cohort of a large number of patients with chronic SCL undergoing robot-assisted gait training, contributing evidence from routine rehabilitation practice. The use of standardized neurological classification (AIS) and objective locomotor assessment enhances the clinical relevance of the findings., Second, it employs an integrated rehabilitation approach, combining Lokomat-assisted gait training with VT, a method rarely investigated in SCL research. This provides new insights into the potential synergistic effects of reflex locomotion and robotic gait training.

Third, the study uses objective, device-generated biomechanical parameters (L-Force, L-ROM, walking speed change, distance change , duration change, BWS change, which enhance the precision and reproducibility of the functional assessments. Lokomat-derived metrics minimize subjectivity and offer a detailed quantification of motor performance beyond conventional clinical scales.

Several limitations must be acknowledged in the study. The follow-up period was relatively short (two weeks), which did not allow sufficient time for a clear or substantial improvement to become evident.

Both the intervention and the assessments were conducted over a short timeframe, limiting the ability to evaluate long-term effects, the sustainability of gains, or delayed changes that typically require extended rehabilitation. Additionally, the relatively short duration of the intervention may have limited the detection of more pronounced changes in muscle strength and joint range of motion.

Limitations of the study include also the retrospective design and significant differences in time since injury between groups – a major limitation factor , which introduced an asymmetry in chronicity. As time since injury strongly influences neuroplastic potential, this imbalance represents an important confounding factor and may contribute to heterogeneity in treatment pathways. A further limitation of this study is the lack of a detailed anatomical characterization of SCL. Although the neurological level of injury was reported using the AIS Scale, imaging data (e.g., MRI) were not systematically available in a standardized format and were therefore not included.

6. Future Directions

Future research should aim to strengthen our findings by conducting comprehensive pre- and post-intervention ROM assessments (active and passive), incorporating stability and postural control tests such as(Berg Balance Test, Trunk Control Test) , utilizing larger sample sizes with randomized blinded controlled designs, including long-term follow-ups, exploring neurophysiological mechanisms through biomechanical and neuroimaging methods, and standardizing protocols and outcome measures for better comparability.

5. Conclusions

The combination of Vojta therapy with Lokomat robotic gait training demonstrated greater improvements in functional and biomechanical parameters compared with Lokomat training alone, supporting its potential role as an effective multimodal strategy for locomotor rehabilitation in patients with spinal cord lesions.

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Institutional Review Board Statement: The study was carried out in accordance with the principles of the Declaration of Helsinki and received approval from the Local Ethics Committee of the Clinical Rehabilitation Hospital Băile Felix. (Approval number: 2087/20.02.2024).

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: The data presented in this study are not publicly available due to privacy and ethical restrictions, as they are archived in the hospital’s institutional database.

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