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CASE REPORT

Progressive functional recovery following technology-assisted neurorehabilitation in a young adult with thoracic spinal cord injury

Arpita Ganguly*

Department of Physiotherapy, Apricot Care Assisted Living & Rehabilitation, Pune, India

***Correspondence:**
Arpita Ganguly,
chatterjee.arpita31@gmail.com

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Background: Traumatic thoracic spinal cord injury (SCI) frequently results in severe impairments in motor function, postural control, mobility and independence. Although spontaneous neurological recovery may occur during the early post-injury period, intensive multidisciplinary rehabilitation incorporating technology-assisted interventions has emerged as a promising strategy to facilitate activity- dependent neuroplasticity and improve functional outcomes. However, detailed longitudinal reports describing structured high-intensity rehabilitation protocols in thoracic SCI remain limited.

Case presentation: A 20-year-old man sustained a traumatic thoracic SCI in a motorcycle accident in December 2024, following which he underwent emergency spinal decompression and posterior instrumentation for stabilization. After achieving medical stability, he was enrolled in a comprehensive inpatient neurorehabilitation program consisting of three to four supervised physiotherapy sessions each day, 6 days per week, over a period of approximately 10 months. The rehabilitation protocol integrated conventional therapeutic exercises with advanced rehabilitation technologies, including robotic-assisted cycling, sensor-based upper- and lower-limb training, progressive trunk control exercises, graded weight-bearing activities, gait retraining, and task-oriented functional practice. Sequential neurological assessments revealed the re-emergence of voluntary motor activity below the neurological level of injury, consistent with clinical progression from a motor-complete to a motor-incomplete SCI. Because a complete follow-up international standards for neurological classification of spinal cord injury (ISNCSCI) examination was unavailable, formal American spinal injury association impairment scale (AIS) reclassification was not performed. Functional improvements were observed across multiple outcome measures, including functional independence measure (FIM) (42/126–57/126), Walking Index for SCI II (0–6), trunk impairment scale (TIS) (2–11), trunk extensor strength (1/5–3/5), lower-limb muscle strength, and pain intensity [visual analogue scale (VAS): 7/10–3/10].

Conclusion: This case demonstrates clinically meaningful neurological and functional recovery following prolonged, high-intensity multidisciplinary rehabilitation incorporating technology-assisted interventions after traumatic thoracic SCI. Although spontaneous recovery and resolution of spinal shock cannot be excluded as contributing factors, the findings support the potential role of individualized, task-specific, high-dose rehabilitation in maximizing functional recovery. Future well-designed prospective studies involving larger patient cohorts are needed to clarify the specific contribution of technology-assisted rehabilitation to functional recovery and to support the development of standardized, evidence-based rehabilitation protocols for individuals with SCI.

Keywords: thoracic spinal cord injury, neurorehabilitation, robotic rehabilitation, gait training, trunk stability, functional recovery, case report

Introduction

Traumatic spinal cord injury (SCI) is a devastating neurological disorder that can lead to permanent impairment of motor, sensory, and autonomic function below the level of the lesion (1–10). The reported global incidence ranges from approximately 10 to 83 cases per million population each year, with road traffic accidents representing one of the most common causes, particularly among young adults (2, 11). Injuries involving the thoracic spinal cord frequently result in significant deficits in trunk stability, sitting balance, postural control, transfers, ambulation, bowel and bladder function, and overall independence in activities of daily living. These impairments often have a profound impact on quality of life and impose considerable long-term healthcare and socioeconomic burdens (2, 3).

Neurological and functional recovery after SCI is a multifactorial process influenced by the extent of the initial injury, neurological completeness, timing of surgical intervention, intrinsic biological recovery, and the quality and intensity of rehabilitation received (2, 3). During the early phases following injury, recovery may occur as spinal shock resolves and spared neural pathways begin to regain function (1, 3). Nevertheless, improvements in neurological status do not necessarily translate into meaningful functional independence. Achieving functional recovery requires structured rehabilitation programs that incorporate repetitive, task-oriented practice to promote motor relearning and activity-dependent neuroplasticity (4–6).

In recent years, technological innovations have become increasingly integrated into neurorehabilitation as an adjunct to conventional physiotherapy. Interventions such as robotic gait training, electromechanical cycling, virtual reality-based rehabilitation, and sensor-assisted feedback systems allow patients to perform large volumes of accurately controlled, repetitive movements while providing objective performance monitoring. These approaches may enhance motor learning, increase patient motivation and engagement, and enable therapists to deliver individualized, high-intensity rehabilitation programs that are difficult to achieve through manual therapy alone (7–10, 12–15).

Although technology-assisted rehabilitation has gained wider acceptance in clinical practice, published evidence describing its incorporation into comprehensive multidisciplinary rehabilitation programs for individuals with thoracic SCI remains limited, particularly in low- and middle-income countries (7, 9, 12). In addition, detailed reports outlining long-term rehabilitation progression, treatment strategies, and serial functional outcomes are relatively uncommon, highlighting the need for further clinical documentation in this area (7, 8).

This CAse REport (CARE)-compliant case report presents the longitudinal neurological and functional recovery of a young adult with traumatic thoracic SCI who participated in an intensive multidisciplinary neurorehabilitation program over approximately 10 months. The rehabilitation approach combined conventional physiotherapy with multiple technology-assisted interventions. The report details the progression of rehabilitation, changes observed across standardized clinical outcome measures, and the importance of serial neurological assessments in documenting recovery over time.

Case presentation

A 20-year-old male with no significant prior medical history sustained a traumatic thoracic SCI as a result of a high-speed motorcycle collision in December 2024. He was initially admitted to a tertiary referral hospital, where emergency spinal decompression followed by posterior stabilization surgery was performed. Based on the operative records and information obtained from the patient and his caregivers, the injury involved the D8–D9 thoracic spinal segments. Following stabilization of his medical condition, he was referred to our specialized neurorehabilitation center in January 2025 for comprehensive inpatient rehabilitation.

On admission, the patient was unable to stand or ambulate and was completely dependent on assistance for bed mobility, transfers, and activities of daily living. Neurological examination revealed severe bilateral lower-limb motor impairment, absent sensory function below the D9 dermatome, markedly reduced trunk control, poor sitting balance, and an inability to maintain standing without support. No voluntary movement was detected in either lower extremity during the initial clinical assessment. Based on these findings, the patient had been classified as having a motor-complete SCI (AIS grade A).

Neurological evaluation performed according to the international standards for neurological classification of spinal cord injury (ISNCSCI) identified the neurological level of injury at T9 with an American spinal injury association impairment scale (AIS) grade A. The upper extremity motor score (UEMS) was 20, whereas the lower extremity motor score (LEMS) was 0. Light touch and pin-prick sensory scores were both 64 out of a maximum of 112. Examination also confirmed the absence of voluntary anal contraction and deep anal pressure, demonstrating a lack of sacral sparing consistent with a complete SCI.

Functional assessment demonstrated extensive disability at the time of admission. The patient scored 42 out of 126 on the Functional Independence Measure (FIM) and 0 on the Walking Index for Spinal Cord Injury II (WISCI-II), indicating complete dependence for mobility. Trunk extensor strength was graded as 1/5 on the medical research council (MRC) scale, while the trunk impairment scale (TIS) score was 2, reflecting severe deficits in trunk stability and postural control. Pain experienced during upright positioning and standing activities was rated as 7/10 on the visual analogue scale (VAS).

An individualized rehabilitation program was developed by the multidisciplinary team with the primary objectives of promoting neurological recovery, improving trunk strength and postural stability, restoring functional mobility, minimizing secondary complications associated with prolonged immobility, alleviating pain, and maximizing independence in activities of daily living.

Timeline of clinical events

Refer to **Table 1** for additional information.

Diagnostic assessment

The diagnosis of traumatic thoracic spinal injury was established based on the patient's clinical presentation, neurological examination, surgical history, and available postoperative imaging. According to available medical records and caregiver history, the injury involved the D8–D9 thoracic spinal region, and the patient underwent emergency surgical decompression with posterior spinal stabilization shortly after the injury.

Radiological evaluation was limited to a postoperative anteroposterior (AP) and lateral radiograph of the thoracolumbar spine (**Figure 1**). The images demonstrated multilevel posterior pedicle screw and rod fixation, with the spinal instrumentation appearing well aligned and without radiographic evidence of hardware loosening or mechanical failure. Comprehensive assessment of the underlying spinal injury was not possible because preoperative computed tomography (CT), magnetic resonance imaging (MRI), operative documentation, and the formal radiology report were unavailable. Consequently, the exact fracture configuration, extent of spinal canal involvement, and precise vertebral levels included in the surgical fixation could not be independently confirmed.

FIGURE 1 | Postoperative anteroposterior (AP) and lateral radiographs demonstrating posterior pedicle screw and rod fixation across the thoracolumbar junction following surgical stabilization of traumatic thoracic spinal cord injury. Only postoperative radiographs were available for review; preoperative CT, MRI, operative notes, and the official radiology report were unavailable. Therefore, detailed radiological interpretation was limited, and neurological recovery was primarily documented through serial clinical examinations and standardized functional outcome measures.

Consequently, radiological interpretation in this report is intentionally limited, and emphasis is placed on serial neurological examinations and standardized functional outcome measures to document recovery.

At admission, neurological assessment documented findings consistent with a motor-complete thoracic SCI (AIS A) based on the clinical examination performed during the early post-injury period. During the subsequent rehabilitation program, serial neurological examinations demonstrated the emergence of voluntary motor activity below the neurological level of injury, indicating recovery from an initially motor-complete presentation to a motor-incomplete clinical presentation. Because a complete follow-up ISNCSCI examination was unavailable, formal AIS reclassification could not be performed. Neurological recovery was therefore described on the basis of serial documented clinical examinations. This limitation is acknowledged and discussed in the manuscript.

TABLE 1 | Timeline of clinical and rehabilitation phases.

Date	Clinical event
December 2024	Road traffic accident resulting in traumatic thoracic spinal cord injury (SCI)
December 2024	Emergency surgical decompression and posterior spinal stabilization
January 2025	Admission to Apricot Care for intensive multidisciplinary neurorehabilitation
January–April 2025	Phase I: Foundational trunk stability, neuromuscular activation, range of motion (ROM), sensory re-education, robotic cycling
April–July 2025	Phase II: Dynamic trunk control, weight-bearing activities, robotic-assisted limb training, supported standing
July–October 2025	Phase III: Progressive gait re-education, strengthening, Hip–Knee–Ankle–Foot Orthosis (HKAFO)-assisted ambulation, task-specific functional training
October 2025	Comprehensive follow-up clinical assessment demonstrating neurological and functional improvement

Therapeutic intervention

Following medical stabilization in January 2025, the patient commenced an individualized multidisciplinary neurorehabilitation program that emphasized high-intensity, goal-directed therapy. The rehabilitation strategy was developed using established principles of task-oriented training, activity-dependent neuroplasticity, progressive loading, and motor relearning to facilitate neurological recovery, improve trunk stability and postural control, restore functional mobility, and maximize independence in activities of daily living (4–10, 14, 15).

Rehabilitation was provided 6 days each week under the supervision of a multidisciplinary team. The patient completed three to four physiotherapy sessions per day, each lasting approximately 45 min, with scheduled rest intervals to reduce fatigue and maintain treatment effectiveness. Conventional physiotherapy formed the foundation of the program and was supplemented with a range of technology-assisted interventions, including robotic cycling, sensor-based upper- and lower-limb training, progressive trunk stabilization exercises, graded weight-bearing activities, gait retraining, and functional task practice (5–10). Exercise dosage, treatment intensity, and task difficulty were continuously modified in response to the patient's neurological progress, functional performance, and exercise tolerance to ensure safe and progressive rehabilitation (6, 14) (**Table 2**).

To facilitate systematic progression, the rehabilitation program was organized into three consecutive phases (**Table 3**). Each phase targeted specific functional objectives while building upon the gains achieved during the preceding stage, allowing rehabilitation to progress in accordance with the patient's evolving clinical status.

Phase I: early rehabilitation (January–April 2025)

Rehabilitation goals

1. Prevent secondary musculoskeletal complications
2. Facilitate neuromuscular activation
3. Improve trunk stability and postural control
4. Maintain joint mobility
5. Promote sensory stimulation
6. Prepare the patient for upright functional activities

During the initial phase, treatment focused on preserving musculoskeletal integrity while facilitating early activation of preserved neuromuscular pathways. Passive and active-assisted range of motion (ROM) exercises were performed for all major joints to maintain flexibility and prevent contractures (16, 17). Progressive trunk stabilization exercises included bridging, rolling, bed mobility training, supported sitting balance activities, and pelvic mobility exercises incorporating anterior, posterior, and lateral weight shifts (18, 19).

To enhance sensorimotor integration, the rehabilitation program incorporated graded sensory stimulation, proprioceptive facilitation, and progressive weight-bearing exercises aimed at increasing afferent input and improving postural awareness (4, 5). Robotic-assisted cycling of the lower extremities was introduced with minimal resistance to facilitate repetitive reciprocal movement, preserve cardiovascular fitness, and provide consistent sensorimotor stimulation throughout the rehabilitation process (9, 12, 20). Upper-extremity strengthening and respiratory conditioning exercises were implemented concurrently to improve overall physical capacity and establish the foundation for progression to more demanding functional rehabilitation activities.

Phase II: intermediate rehabilitation (April–July 2025)

Rehabilitation goals

1. Improve dynamic trunk control
2. Develop weight-bearing tolerance
3. Enhance postural alignment
4. Initiate functional standing
5. Facilitate lower-limb motor recovery

As the patient's voluntary trunk control improved, the rehabilitation program advanced to activities requiring greater postural stability and functional performance. Training emphasized dynamic sitting balance, multidirectional reaching, quadruped and tall-kneeling positions, and progressively resisted weight-shifting exercises to enhance trunk stability, pelvic alignment, and activation of the proximal musculature (18, 19).

Technology-assisted interventions were expanded through repetitive upper- and lower-extremity training using the Rymo-MOBI-L portable robotic rehabilitation system. The device delivered real-time visual feedback, enabling precise movement practice while supporting motor relearning, improving movement quality, and encouraging active patient participation throughout therapy (8–10, 21). Supported standing was gradually introduced using a body-weight support system in conjunction with parallel bars to promote symmetrical lower-limb loading, optimize postural alignment, enhance proprioceptive feedback, and progressively increase tolerance to upright weight-bearing activities (6, 10, 22–24).

Resistance training for the trunk and upper extremities was advanced in a graded manner using resistance bands, free weights, and functional closed-chain exercises. Repetitive

TABLE 2 | Structured neurorehabilitation program-based on the frequency, intensity, time and type (FITT) principle.

Phase	Frequency	Intensity	Time	Type of intervention	Primary goals
Phase I (Jan–Apr 2025)	6 days/week; 3 sessions/day	Low to moderate	45 min/session	ROM exercises, trunk stabilization, pelvic mobility, sensory stimulation, robotic-assisted cycling, bed mobility, respiratory exercises	Prevent secondary complications, initiate neuromuscular activation, improve trunk stability
Phase II (Apr–Jul 2025)	6 days/week; 4 sessions/day	Moderate	45 min/session	Dynamic sitting balance, quadruped, tall kneeling, Rymo robotic training, supported standing, strengthening, transfer training	Improve postural control, increase weight-bearing tolerance, develop functional mobility
Phase III (Jul–Oct 2025)	6 days/week; 4 sessions/day	Moderate to high	45 min/session	HKAFO-assisted gait training, robotic cycling, progressive strengthening, balance retraining, ADL training, caregiver education	Improve gait, endurance, functional independence, and community mobility

TABLE 3 | Clinical and functional outcomes following 10 months of rehabilitation.

Outcome measure	Baseline (January 2025)	Final assessment (October 2025)	Clinical interpretation
American spinal injury association impairment scale (AIS) classification	Motor-complete presentation (AIS A at admission)	Recovery of voluntary motor function below the neurological level of injury	Findings indicate a transition to a motor-incomplete clinical presentation; formal AIS reclassification not performed
Functional independence measure (FIM)	42/126	57/126	Improved independence in daily activities
Walking index for SCI II (WISCI-II)	0	6	Progression to assisted overground ambulation
Hip flexor strength (MRC)	0/5	2/5	Recovery of voluntary motor activity
Hip extensor strength (MRC)	0/5	1/5	Emerging proximal lower-limb control
Ankle dorsiflexor strength (MRC)	0/5	1/5	Initial distal motor recovery
Trunk extensor strength (MRC)	1/5	3/5	Improved postural stability
Trunk impairment scale (TIS)	2	11	Significant improvement in trunk control
Pain (VAS)	7/10	3/10	Reduced pain during functional activities

Abbreviations: AIS, American spinal injury association impairment scale; FIM, functional independence measure; WISCI-II, walking index for spinal cord injury II; MRC, medical research council; VAS, visual analogue scale.
Note: Neurological improvement to AIS C was determined from serial clinical neurological examinations documenting recovery of voluntary motor function below the neurological level of injury. A complete follow-up international standards for neurological classification of spinal cord injury (ISNCSCI) examination was unavailable.

practice of bed mobility and transfer activities was incorporated to improve functional independence and reduce the level of physical assistance required during everyday mobility tasks (16, 17).

Phase III: advanced rehabilitation (July–October 2025)

Rehabilitation goals

1. Restore functional ambulation
2. Improve lower limb strength and endurance
3. Enhance gait quality
4. Increase functional independence
5. Promote community mobility

The final rehabilitation phase emphasized task-specific gait training and functional mobility. Progressive overground gait training was performed using a Hip–Knee–Ankle–Foot Orthosis (HKAFO) with therapist assistance. Advanced gait training also incorporated the Opton NeuroWalker to progressively reduce external support while improving dynamic balance, weight shifting, and overground walking ability.

Gait parameters, including step length, cadence, weight transfer, and walking endurance, were progressively advanced according to patient tolerance (10, 22, 23, 25).

Lower extremity strengthening focused on the hip flexors, extensors, knee musculature, ankle dorsiflexors, and trunk stabilizers through progressive resistance exercises and functional closed-chain activities Robotic-assisted cycling sessions (15–20 min) using the Oxy Cycle Sync (Biotronics Care International) were continued to improve lower-limb coordination, cardiorespiratory endurance, and repetitive locomotor practice (9, 12, 26).

Task-specific functional training incorporated sit-to-stand practice, transfer training, balance retraining, stair simulation, and activities of daily living, with the objective of maximizing independence in home and community environments (6, 24). Patient and caregiver education regarding positioning, pressure-relief strategies, home exercise progression, fall prevention, and safe mobility techniques was provided throughout the rehabilitation program to facilitate long-term self-management following discharge (16, 17).

Outcome measures including the FIM, WISCI-II, TIS, MRC muscle strength grading, and VAS were prospectively recorded during routine clinical assessments at baseline and at the final rehabilitation assessment as part of Standard patient care.

Results and outcomes

Following approximately 10 months of intensive multidisciplinary neurorehabilitation, the patient demonstrated clinically meaningful improvements in neurological status, trunk control, lower-limb motor function, mobility, pain, and functional independence. Recovery was documented through serial neurological examinations and standardized outcome measures performed throughout the rehabilitation program.

At admission (January 2025), the patient presented with findings consistent with a motor-complete thoracic spinal cord injury (AIS A) (1), profound bilateral lower-extremity weakness, absent sensation below the D9 neurological level, poor trunk control, and complete dependence for ambulation. During the rehabilitation period, serial neurological examinations demonstrated the emergence of voluntary motor activity below the neurological level of injury, indicating recovery from a motor-complete to a motor-incomplete clinical presentation. Because a complete follow-up ISNCSCI examination was unavailable, formal AIS reclassification could not be confirmed. Neurological recovery was therefore documented using serial clinical examinations together with standardized functional outcome measures (1) (**Table 4**).

TABLE 4 | ISNCSCI table pre and post.

ISNCSCI variable	Baseline (January 2025)	10-month follow-up
Neurological level of injury	T9	T9*
AIS grade	A	Clinical motor-incomplete presentation[a]
UEMS	50/50	50/50
LEMS	0/50	Not formally reassessed
Light touch	64/112	74/112
Pin prick	64/112	64/112
VAC	Absent	Not formally reassessed
DAP	Absent	Not formally reassessed
Sacral sparing	Absent	Not formally reassessed

[a]Follow-up neurological status was based on serial clinical examinations because a complete repeat ISNCSCI assessment was unavailable.

FIM scores improved from 42/126 at baseline to 57/126 at the final assessment, reflecting greater independence in bed mobility, transfers, self-care, and mobility-related activities (27). Similarly, the WISCI-II improved from 0 to 6, indicating progression from an inability to ambulate to assisted overground walking using an orthotic device and therapist support (28).

Progressive recovery of voluntary lower-limb motor function was observed throughout rehabilitation. Hip flexor strength improved from 0/5 to 2/5, hip extensor strength from 0/5 to 1/5, and ankle dorsiflexor strength from 0/5 to 1/5 according to the Medical Research Council grading system (29). Trunk extensor strength improved from 1/5 to 3/5, accompanied by a marked increase in the TIS score from 2 to 11, demonstrating enhanced trunk stability, postural control, and sitting balance (18).

Pain intensity during upright activities decreased substantially from 7/10 to 3/10 on the VAS (30), enabling longer therapy sessions, improved standing tolerance, and greater participation in task-specific rehabilitation. Clinically, the patient progressed from requiring maximal assistance for most functional activities to performing bed mobility with greater independence, improved transfer ability, prolonged unsupported sitting, supported standing, and HKAFO-assisted overground gait training under therapist supervision.

In addition to physical improvements, the patient demonstrated enhanced motivation, active participation, and adherence throughout the rehabilitation program. The incorporation of technology-assisted interventions providing real-time visual feedback and repetitive task practice appeared to improve engagement and facilitate consistent participation during therapy sessions (8–10, 12). However, because this is a single case report without a comparator, these observations should be interpreted descriptively rather than as evidence of a causal treatment effect.

Overall, the patient achieved clinically meaningful neurological and functional recovery over the 10-month rehabilitation period, with improvements observed across impairment-, activity-, and participation-level outcomes. While spontaneous neurological recovery, resolution of spinal shock, surgical intervention, and intensive rehabilitation likely contributed collectively to these gains (2–6), the structured multidisciplinary program facilitated

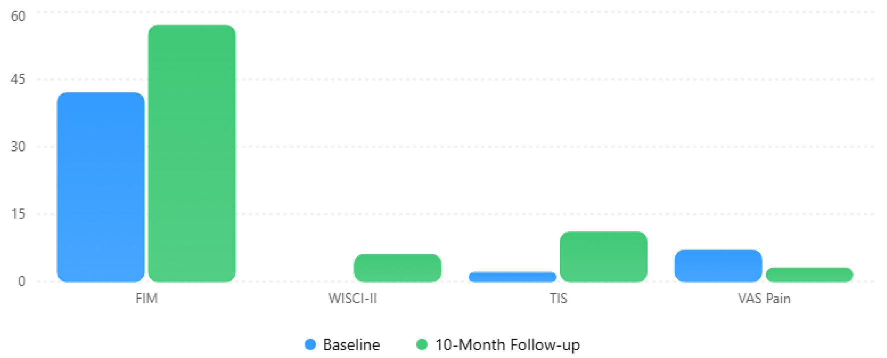

FIGURE 2 | Comparison of key clinical and functional outcomes between baseline assessment (January 2025) and 10-month follow-up (October 2025). Improvements were observed in functional independence (FIM), walking capacity (WISCI-II), and trunk control (TIS), while pain intensity (VAS) decreased over the rehabilitation period. The patient also demonstrated recovery of voluntary motor function below the neurological level of injury, indicating a transition from a motor-complete to a motor-incomplete clinical presentation, together with emergence of voluntary lower-limb motor activity.

progressive translation of neurological improvements into meaningful functional abilities (**Figure 2**).

Discussion

This case demonstrated improvements that extended beyond the prevention of secondary complications, with measurable gains observed in neurological function, trunk control, ambulation, and overall functional independence. Following approximately 10 months of intensive multidisciplinary neurorehabilitation, the patient showed clinically meaningful recovery across multiple standardized outcome measures. Serial neurological examinations identified the emergence of voluntary motor activity below the neurological level of injury, suggesting progression from an initially motor-complete to a motor-incomplete clinical presentation. However, because a complete follow-up ISNCSCI examination was not available, these findings should not be interpreted as a formal change in AIS classification. The improvements observed were likely influenced by several interacting factors, including spontaneous neurological recovery, early surgical management, resolution of spinal shock, and participation in a structured, high-intensity rehabilitation program (2–6).

Functional recovery after SCI is governed by a complex interplay of intrinsic biological repair mechanisms and rehabilitation-induced neuroplasticity. Resolution of secondary injury processes, preservation of residual neural pathways, and repetitive task-oriented practice collectively contribute to motor recovery and functional improvement. Experimental and clinical studies have demonstrated that intensive, goal-directed rehabilitation can enhance corticospinal reorganization, reinforce motor learning, and promote activity-dependent neuroplasticity through repeated voluntary movement and enriched sensory input (4–6, 15, 20, 31–33). Consequently, contemporary neurorehabilitation increasingly emphasizes intensive, individualized interventions that provide a high volume of meaningful repetitions while maintaining patient engagement and active participation (6, 8, 14).

A distinctive aspect of the present case was the sustained delivery of high-dose rehabilitation, consisting of three to four supervised physiotherapy sessions per day, 6 days each week, over approximately 10 months. The rehabilitation program was progressively advanced according to the patient's neurological recovery, exercise tolerance, and functional capabilities. Rather than addressing isolated impairments, the intervention targeted multiple domains simultaneously, including trunk stability, postural control, sensorimotor integration, strengthening, balance, gait retraining, and activities of daily living, thereby supporting recovery at both impairment and functional levels (6, 14, 16, 17).

Integration of technology-assisted rehabilitation

An important feature of the rehabilitation program was the incorporation of multiple technology-assisted interventions as complementary components of therapist-directed physiotherapy. The selection and progression of each technology were individualized according to the patient's stage of recovery and therapeutic goals, allowing delivery of intensive, repetitive, and task-oriented practice while maintaining active patient involvement throughout rehabilitation (6–10).

Rymo-MOBI-L portable robotic rehabilitation system

Rehabilitation of both the upper and lower extremities incorporated the Rymo-MOBI-L portable robotic rehabilitation system, an end-effector–based device that enabled repetitive, therapist-supervised movement training with adjustable levels of assistance and resistance (21).

Training parameters were individualized according to the patient's neurological status and motor capabilities, allowing exercise difficulty to be progressively increased as voluntary motor control improved. Throughout each session, the system delivered real-time visual feedback on movement characteristics, including ROM, movement speed, repetition count, accuracy, and task completion, thereby promoting active participation and facilitating motor relearning through intensive, repetitive practice (4, 8, 9, 12). The quantitative performance data generated during therapy also provided objective measures of patient progress, enabling clinicians to monitor recovery and refine the rehabilitation program over time.

Oxy Cycle Sync (Biotronics Care International)

The Oxy Cycle Sync robotic cycling system (Biotronics Care International) (26) was incorporated into lower-extremity rehabilitation during the early and intermediate phases of treatment. The device facilitates repetitive reciprocal cycling movements under therapist supervision, enabling maintenance of joint mobility, cardiovascular conditioning, and continuous sensorimotor stimulation while increasing the overall volume of therapeutic practice (9, 12). Repetitive reciprocal movement also provides sustained afferent input and rhythmic muscle activation, mechanisms which facilitates locomotor recovery by stimulating spinal locomotor networks, including central pattern generators (5, 9, 15, 20). As neurological recovery progressed, both exercise resistance and training duration were gradually increased to improve muscular endurance and lower-limb conditioning.

Galanto Arm & Chest Module (Galanto Technologies)

To address deficits in trunk control and postural stability, rehabilitation incorporated the Galanto Arm & Chest Module (Galanto Technologies, India) (34). The patient performs interactive virtual reality–based activities while seated on an unstable support surface and wearing upper-body motion sensors. These exercises require multidirectional reaching, trunk rotation, controlled weight shifting, and coordinated upper-extremity movements within a gamified environment. Such activities simultaneously challenge dynamic sitting balance, anticipatory postural control, trunk stability, and upper-limb coordination while providing continuous visual and proprioceptive feedback (12, 13, 18, 19). Exercise difficulty is progressively increased by modifying task complexity, reaching distance, movement speed, session duration, and surface instability, enabling graded progression throughout rehabilitation. The interactive nature of the training promotes sustained engagement while facilitating a high volume of functional movement repetitions.

Opton Gait Trainer

As postural control and lower-extremity strength improved, locomotor rehabilitation progressed to the Opton Gait Trainer (35). This body-weight-supported gait training system enabled repetitive stepping practice within a controlled environment, reducing therapist workload while allowing safe initiation of gait training. The device promoted symmetrical weight transfer, upright posture, controlled loading of the lower extremities, and repetitive stepping practice, thereby increasing locomotor training intensity beyond that achievable with conventional overground walking alone (6, 10, 22–24). Training parameters, including walking speed, duration, and body-weight support, were progressively adjusted according to the patient's functional recovery and tolerance.

Opton NeuroWalker

During the later stages of rehabilitation, overground gait training was advanced using the Opton NeuroWalker (36), which provides adjustable external support to facilitate upright ambulation according to the patient's balance and lower-limb control. As trunk stability, voluntary motor activity, and weight-bearing capacity improved, the level of external assistance was gradually reduced, enabling progression toward more independent walking. The integration of repetitive gait practice with dynamic balance training supported the transition from supported locomotion to increasingly functional overground ambulation while maintaining patient safety throughout rehabilitation (6, 22, 23).

Conventional physiotherapy remained the foundation

Although technology-assisted interventions constituted a key element of the rehabilitation program, they were implemented as adjuncts to, rather than substitutes for, conventional physiotherapy. Throughout the rehabilitation process, therapist-led interventions—including manual facilitation, trunk stabilization training, progressive strengthening exercises, transfer practice, balance retraining, postural correction, HKAFO-assisted gait training (25), task-oriented functional activities, and structured caregiver education—remained central to patient management (16, 17).

Integrating therapist-guided rehabilitation with technology-assisted modalities allowed the delivery of intensive, repetitive, and progressively graded practice while ensuring that treatment remained individualized and responsive to the patient's evolving neurological status, functional abilities, and rehabilitation goals (4–10).

Clinical significance

Improvements observed in the TIS, FIM, WISCI-II, lower-extremity muscle strength, and pain intensity indicate that neurological recovery was accompanied by clinically relevant gains in functional ability (18, 27–30). The marked improvement in trunk control may have served as a key prerequisite for enhanced postural stability, facilitating subsequent progress in standing, transfer performance, balance, and gait. This observation is consistent with previous reports emphasizing the importance of proximal trunk stability as a foundation for successful locomotor rehabilitation (18, 19).

A further consideration in the interpretation of this case is the recovery of voluntary motor activity below the neurological level of injury during the rehabilitation period. These serial clinical findings suggest progression from an initially motor-complete presentation to a motor-incomplete clinical presentation, highlighting the dynamic nature of neurological recovery following traumatic SCI.

Because the initial neurological examination was performed during the acute post-injury period, spinal shock may have influenced the apparent completeness of injury. Furthermore, a complete follow-up ISNCSCI examination was unavailable. Accordingly, neurological recovery was described using serial documented clinical examinations rather than a formal repeat ISNCSCI classification (1, 2).

Finally, although this case illustrates the feasibility and potential benefits of integrating multiple rehabilitation technologies into a comprehensive SCI program, causality cannot be established. Recovery was likely influenced by a combination of spontaneous neurological recovery, early surgical management, patient motivation, family support, intensive conventional physiotherapy, orthotic-assisted gait training, and technology-assisted rehabilitation (2–10). Future prospective studies with standardized neurological assessments, objective gait analysis, and larger cohorts are required to determine the independent contribution of individual rehabilitation technologies.

Strengths

This case report has several strengths. First, it provides a comprehensive longitudinal description of approximately 10 months of intensive multidisciplinary neurorehabilitation following traumatic thoracic SCI. Second, rehabilitation was delivered using a structured, progressive, phase-based protocol integrating conventional physiotherapy with multiple technology-assisted interventions, including the Rymo-MOBI-L robotic rehabilitation system, Oxy Cycle Sync robotic cycle, Galanto Arm & Chest virtual reality module, Opton Gait Trainer, Opton NeuroWalker, and HKAFO-assisted gait training (21, 25, 26, 34–36). Detailed reporting of rehabilitation intensity, progression and clinical reasoning enhances the reproducibility of the intervention for clinicians and researchers.

Another strength is the use of multiple standardized outcome measures, including the FIM (27), WISCI-II (28), TIS (18), MRC muscle strength grading (29), VAS (30), and serial neurological examinations using ISNCSCI principles (1), enabling comprehensive evaluation across impairment and activity domains. Finally, this report demonstrates the feasibility of integrating advanced rehabilitation technologies into routine multidisciplinary clinical practice within an Indian neurorehabilitation setting.

Limitations

Several limitations should be considered when interpreting this report.

First, this is a single patient case report; therefore the findings cannot be generalized to the broader SCI population and should be interpreted as hypothesis generatingrather than confirmatory evidence.

Second, preoperative CT, MRI, operative notes, and the official radiological report were unavailable because the patient underwent emergency surgical management at another institution. Consequently, radiological interpretation was limited to the available postoperative AP and lateral radiographs.

Third, although serial neurological examinations documented recovery of voluntary motor function below the neurological level of injury, a complete follow-up ISNCSCI examination was unavailable. Therefore, although serial neurological examinations documented recovery of voluntary motor function below the neurological level of injury, a formal repeat ISNCSCI examination was unavailable, and formal AIS reclassification could not be confirmed (1).

Fourth, because rehabilitation incorporated multiple simultaneous interventions—including conventional physiotherapy, Rymo-MOBI-L robotic-assisted rehabilitation, Galanto virtual reality-based trunk training, Oxy Cycle Sync robotic cycling, Opton Gait Trainer, Opton NeuroWalker, HKAFO-assisted gait training, and multidisciplinary care—the independent contribution of any individual intervention cannot be determined (6–10, 12, 21, 25, 26, 34–36).

Long-term follow-up after discharge was unavailable; therefore, durability of the observed improvements could not be evaluated.

Although FIM, WISCI-II, TIS, MRC grading, and VAS were routinely documented during rehabilitation, a complete repeat ISNCSCI assessment was unavailable at the final evaluation, limiting standardized neurological comparison over time.

The clinical improvements observed in this case were most likely influenced by multiple interacting factors, including spontaneous neurological recovery, resolution of spinal shock, timely surgical decompression, patient motivation, caregiver involvement, and the delivery of an intensive rehabilitation program (2–6). Consequently, the relative contribution of any individual technology-assisted intervention cannot be determined from this single case report. Future prospective controlled studies involving larger patient populations, standardized neurological evaluations, and objective biomechanical outcome measures are warranted to clarify the specific effects of individual rehabilitation technologies and to better inform evidence-based clinical practice (6–10).

Although FIM, WISCI-II, TIS, MRC grading and VAS were routinely documented during rehabilitation, a complete repeat ISNSCI assessment was unavailable at the final evaluation, limiting standardized neurological comparison over time.

Clinical implications

This case highlights several important considerations for neurorehabilitation following traumatic thoracic SCI.

Early initiation of intensive, individualized, multidisciplinary rehabilitation may facilitate meaningful improvements in neurological function, trunk control, mobility, and independence (5, 6, 16, 17). The integration of technology-assisted rehabilitation within conventional physiotherapy enabled delivery of high-repetition, task-specific practice while maintaining active patient participation, therapist supervision, and progressive treatment advancement (6–10, 12, 21, 26, 34–36).

Importantly, recovery of trunk stability appeared to precede improvements in standing, transfers, and gait, reinforcing the fundamental role of proximal postural control in functional locomotor rehabilitation (18, 19, 37, 38).

Although evidence from a single case cannot establish treatment efficacy, the rehabilitation strategy described in this report may serve as a practical framework for clinicians designing comprehensive, technology-assisted rehabilitation programs for individuals with thoracic SCI, particularly in specialized rehabilitation centers equipped with advanced neurorehabilitation technologies (6–10).

Conclusion

This CARE-compliant case report describes clinically meaningful neurological and functional recovery in a young adult with traumatic thoracic SCI following approximately 10 months of high-intensity multidisciplinary neurorehabilitation integrating conventional physiotherapy with multiple technology-assisted interventions.

Clinically meaningful improvements were observed in trunk control, lower-extremity motor function, gait, pain, functional independence, and overall mobility, while serial neurological examinations demonstrated recovery of voluntary motor function below the neurological level of injury, indicating a transition from a motor-complete to a motor-incomplete clinical presentation. Because a complete follow-up ISNCSCI examination was unavailable, formal AIS reclassification could not be confirmed (1).

Although spontaneous neurological recovery, early surgical management, and resolution of spinal shock likely contributed to the patient's recovery (2, 3), the findings support the feasibility of integrating robotic rehabilitation, virtual reality-based trunk training, robotic-assisted cycling, body-weight-supported gait training, and orthotic-assisted ambulation within a structured, progressive, multidisciplinary rehabilitation program (6–10, 12, 21, 25, 26, 34–36).

Future prospective controlled studies employing standardized ISNCSCI assessments, objective gait analysis, advanced imaging, and larger patient cohorts are required to determine the independent contribution of technology-assisted rehabilitation and to establish evidence-based protocols for optimizing recovery following traumatic SCI (1, 6–10).

Data availability

The datasets generated and analysed during the current case report are not publicly available because of patient confidentiality but are available from the corresponding author upon reasonable request.

Ethics statement

Ethics approval was waived because this report describes a single anonymized patient treated as part of routine clinical care, in accordance with institutional policy and applicable national guidelines.

Consent for publication

Written informed consent was obtained from the patient for publication of this case report, including anonymized clinical information and the accompanying postoperative radiographic image. A copy of the signed consent is available for review by the editor upon reasonable request.

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Conflict of interest

The author declares that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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