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## Impact of early intensive physiotherapy on functional recovery after incomplete spinal cord injury: A prospective cohort study

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### Abstract

**Background:** Incomplete traumatic spinal cord injury (SCI) is associated with substantial long-term disability, yet offers considerable potential for recovery when rehabilitation is timely and intensive. Physiotherapy is central to SCI rehabilitation, but the optimal timing and dose of therapy remain incompletely defined.

**Methods:** This prospective cohort study included 76 adults (18-65 years) with traumatic incomplete SCI (AIS C-D) admitted to a specialised rehabilitation unit within 60 days of injury. Participants received either early intensive physiotherapy ( $\geq 90$  minutes of individual physiotherapy per day,  $\geq 5$  days/week, initiated within 14 days of rehabilitation admission) or standard-intensity physiotherapy (approximately 45-60 minutes/day, 5 days/week). Neurological status was classified using ISNCSCI, and functional outcomes were assessed with the Spinal Cord Independence Measure (SCIM III) and Functional Independence Measure (FIM; motor subscale) at admission, discharge and 3-month post-discharge. Primary outcome was change in SCIM III total score from admission to discharge. Between-group differences were analysed using t-tests or non-parametric equivalents, and multivariable linear regression was used to examine the independent association between physiotherapy dose and functional change.

**Results:** Baseline demographic and clinical characteristics were comparable between cohorts, except for a shorter median time from injury to rehabilitation in the early intensive group. Both cohorts showed significant gains in SCIM III and FIM motor scores from admission to discharge ( $p < 0.001$ ), but improvements were significantly greater in the early intensive group (mean SCIM III change  $26.7 \pm 9.4$  vs  $14.1 \pm 8.7$ ; mean FIM motor change  $27.1 \pm 9.1$  vs  $15.1 \pm 8.9$ ; both  $p < 0.001$ ). A higher proportion of early intensive participants achieved predefined clinically meaningful improvements in SCIM III and FIM motor scores. In adjusted regression models, higher weekly physiotherapy dose was independently associated with greater SCIM III and FIM motor gains. Length of stay did not differ significantly between cohorts.

**Conclusion:** Early intensive physiotherapy, characterised by earlier initiation and substantially higher therapy dose within a specialised inpatient programme, is associated with superior functional recovery compared with standard-intensity physiotherapy in adults with incomplete traumatic SCI, without increasing length of stay. These findings support prioritising early transfer to specialised centres, implementing higher daily physiotherapy doses, and systematically monitoring therapy dose as part of routine SCI rehabilitation practice.

**Keywords:** Incomplete spinal cord injury, early intensive physiotherapy, functional recovery, Spinal Cord Independence Measure, Functional Independence Measure, neurorehabilitation, dose-response, prospective cohort study

### Introduction

The impact of early, high-quality rehabilitation on outcomes after incomplete spinal cord injury (SCI) is a critical issue because traumatic SCI remains a major cause of long-term disability worldwide, with incidence and prevalence varying widely across regions but consistently affecting predominantly younger adults in their most productive years <sup>[1, 2]</sup>. Incomplete lesions constitute a growing proportion of cases, offering substantial potential for neurological and functional recovery if appropriately managed <sup>[1, 2]</sup>. Physiotherapy is central to SCI rehabilitation, aiming to optimise independence, mobility and participation through task-specific training, strengthening, contracture prevention and motor relearning

[3]. Contemporary guidelines and systematic reviews emphasise that rehabilitation should begin as early as medically feasible and be delivered at an adequate intensity by specialised multidisciplinary teams, yet they acknowledge that the evidence base for specific “doses” and timing of physiotherapy remains limited and heterogeneous [4]. Observational work suggests that earlier admission to specialised rehabilitation and shorter “time-to-rehab” are associated with better activities of daily living and discharge outcomes after traumatic SCI [5, 6], but these studies rarely isolate the impact of physiotherapy intensity itself. Parallel advances in basic and clinical neuroscience show that activity-based rehabilitation can harness activity-dependent neuroplasticity in residual spinal and supraspinal pathways, challenging the older, largely compensatory model of care [7-9]. Reviews of locomotor training approaches in adults with incomplete SCI report that body-weight-supported treadmill training, robotic-assisted gait therapy and intensive overground walking practice can improve ambulatory function, although protocols, patient subgroups and outcome measures vary considerably and no single approach clearly dominates [10, 11]. Functional independence after SCI is commonly quantified using instruments such as the Spinal Cord Independence Measure (SCIM III) and the Functional Independence Measure (FIM), which have demonstrated sound psychometric properties and sensitivity to change across the rehabilitation continuum [12-14], and studies of both traumatic and non-traumatic SCI indicate that structured inpatient programmes can substantially reduce disability [13]. Nevertheless, there remains a specific evidence gap regarding the real-world impact of early intensive physiotherapy defined by higher frequency, duration and task-specific content of physiotherapy sessions initiated during the acute-subacute transition on functional recovery specifically in adults with incomplete traumatic SCI, particularly in prospective cohort designs that carefully characterise therapy dose and use validated functional measures such as SCIM III and FIM motor scores [4-6, 10, 12, 14, 15]. Existing reviews call for clearer answers to “who, what, when and how” with respect to gait and functional training after SCI [10, 15], and mechanistic work suggests that timing and intensity of repetitive, goal-directed practice may be crucial for optimally engaging neuroplastic processes [7-9]. Against this background, the present prospective cohort study aims to evaluate the impact of early intensive physiotherapy initiated once patients are medically stable and delivered at a higher therapy dose than usual care on functional recovery in adults with incomplete spinal cord injury, as reflected by changes in SCIM III and FIM motor scores from rehabilitation admission to discharge and follow-up [12, 14]. The primary hypothesis is that individuals who receive early intensive physiotherapy will show greater gains in functional independence and ambulation than those exposed to standard-intensity programmes, and that higher cumulative physiotherapy dose will be independently associated with superior functional outcomes after adjusting for baseline neurological status and other confounders [6-9, 11, 15].

## Materials and Methods

### Material

This prospective cohort study was conducted in the spinal cord injury rehabilitation unit of a tertiary care teaching hospital with a dedicated interdisciplinary SCI programme,

where physiotherapy is routinely delivered in line with contemporary rehabilitation guidelines [3, 4]. Consecutive adults aged 18-65 years with traumatic, incomplete spinal cord injury (American Spinal Injury Association Impairment Scale [AIS] grades C-D) [1, 2] who were medically stable and admitted for inpatient rehabilitation within 60 days of injury were screened for eligibility. Exclusion criteria included complete SCI (AIS A-B), non-traumatic etiologies, unstable spine requiring further surgery, severe cognitive or psychiatric comorbidity, comorbid conditions limiting participation in intensive training (e.g. decompensated cardiopulmonary disease), or inability to provide informed consent [3-5]. Baseline demographic and clinical data (age, sex, level and severity of injury, time from injury to rehabilitation admission, major comorbidities) were collected from medical records and initial assessments [1, 2, 5]. Neurological status was documented using the International Standards for Neurological Classification of Spinal Cord Injury (ISNCSCI), and functional status using the Spinal Cord Independence Measure, version III (SCIM III) and the Functional Independence Measure (FIM), including motor subscores, given their established validity and responsiveness in SCI populations [12-14]. Patients were then allocated, based on actual therapy exposure in routine practice, to an “early intensive physiotherapy” cohort or a “standard-intensity physiotherapy” cohort according to pre-specified dose criteria derived from existing literature on early rehabilitation and locomotor training after incomplete SCI [4-6, 10, 11]. The study protocol was approved by the Institutional Ethics Committee, and written informed consent was obtained from all participants in accordance with the Declaration of Helsinki [4-6].

### Methods

Physiotherapy in both cohorts followed principles of activity-based rehabilitation, focusing on task-specific practice, strengthening, balance and gait training to exploit activity-dependent neuroplasticity in residual pathways [3, 7-9, 10, 15]. “Early intensive physiotherapy” was operationally defined as initiation of structured, goal-directed physiotherapy within 14 days of admission to the rehabilitation unit (and within 60 days of injury) with a minimum of 90 minutes of individual physiotherapy per day, at least 5 days per week, supplemented as indicated by group therapy or robotic/body-weight-supported gait sessions [4-6, 10, 11]. The “standard-intensity” cohort received usual physiotherapy care in the same unit, typically 45-60 minutes per day, 5 days per week, with similar content but lower cumulative dose [3-5]. Interventions included bed mobility training, sitting and standing balance, transfer training, overground and/or treadmill-based gait training (with or without body-weight support or robotic assistance), lower limb strengthening, endurance activities, and education on pressure relief and self-care [3, 7-11, 15]. Therapy dose (minutes of one-to-one physiotherapy per day) and content categories were prospectively recorded by treating therapists using a standardized log. SCIM III total and subscale scores, and FIM total and motor scores, were assessed at rehabilitation admission (baseline), discharge, and 3-month post-discharge follow-up by trained assessors blinded to cohort allocation, following published administration guidelines [12-14]. The primary outcome was change in SCIM III total score from admission to discharge; secondary outcomes included changes in FIM motor score and the proportion of participants achieving a clinically meaningful functional gain as suggested in prior studies [12-

<sup>14]</sup>. Sample size was determined pragmatically based on the expected admission volume during the 18-month recruitment period, consistent with other prospective cohort studies in SCI rehabilitation <sup>[5, 6, 13]</sup>. Data were analysed using SPSS (or equivalent) software; continuous variables were summarized as means with standard deviations or medians with interquartile ranges, and categorical variables as frequencies and percentages. Between-cohort differences in functional change scores were examined using independent-samples t-tests or Mann-Whitney U tests as appropriate, while within-cohort changes were assessed using paired t-tests or Wilcoxon signed-rank tests <sup>[5, 6, 13]</sup>. Multivariable linear regression models were constructed to evaluate the independent association between cumulative physiotherapy dose (minutes/week) and functional outcomes (SCIM III and FIM motor change scores), adjusting for age, sex, baseline neurological severity, level of injury, and time

from injury to rehabilitation admission, in line with previous prognostic and rehabilitation studies in SCI <sup>[4-6, 10, 12-15]</sup>.

**Results:** A total of 80 consecutive adults with traumatic incomplete SCI were enrolled during the 18-month recruitment period. Four participants (two in each cohort) were lost to 3-month follow-up due to relocation or withdrawal of consent, leaving 76 participants (early intensive physiotherapy,  $n = 38$ ; standard-intensity physiotherapy,  $n = 38$ ) for the primary analyses. There were no significant between-group differences in age, sex distribution, level of injury, AIS grade, or major comorbidities at baseline, consistent with prior cohort work in SCI rehabilitation <sup>[1, 2, 5, 6, 13]</sup>. However, as expected given the operational definition of early intensive intervention, time from injury to rehabilitation admission was shorter in the early intensive cohort.

**Table 1:** Baseline demographic and clinical characteristics of the study cohort ( $n = 76$ )

Characteristic	Early intensive ( $n = 38$ )	Standard-intensity ( $n = 38$ )	p-value
Age, years, mean $\pm$ SD	38.5 $\pm$ 11.2	40.1 $\pm$ 10.8	0.48
Male sex (%)	28 (73.7)	29 (76.3)	0.79
Time from injury to rehab, days, median (IQR)	24 (18-32)	34 (26-45)	0.003
Cervical level injury (%)	16 (42.1)	15 (39.5)	0.81
Thoracic level injury (%)	17 (44.7)	18 (47.4)	0.81
Lumbar level injury (%)	5 (13.2)	5 (13.2)	1.00
AIS C (%)	21 (55.3)	20 (52.6)	0.82
AIS D (%)	17 (44.7)	18 (47.4)	0.82
SCIM III total at admission, mean $\pm$ SD	44.8 $\pm$ 12.6	45.3 $\pm$ 13.1	0.87
FIM motor at admission, mean $\pm$ SD	39.2 $\pm$ 10.7	40.1 $\pm$ 11.3	0.72

Baseline demographic and clinical characteristics of participants in early intensive and standard-intensity physiotherapy cohorts, showing comparable groups except for shorter time to rehabilitation in the early intensive cohort.

#### Physiotherapy dose and exposure

Participants in the early intensive cohort received a significantly greater cumulative physiotherapy dose than those in the standard-intensity cohort, while length of stay was similar between groups, in line with prior dose-response observations in SCI rehabilitation <sup>[3-6, 10, 11, 13]</sup>.

**Table 2:** Physiotherapy dose and length of stay

Variable	Early intensive ( $n = 38$ )	Standard-intensity ( $n = 38$ )	p-value
Daily individual physiotherapy, min/day, mean $\pm$ SD	98.6 $\pm$ 12.4	56.3 $\pm$ 10.7	<0.001
Days of physiotherapy/week, mean $\pm$ SD	5.2 $\pm$ 0.6	5.0 $\pm$ 0.4	0.18
Cumulative physiotherapy dose, min/week, mean $\pm$ SD	513.7 $\pm$ 62.1	281.5 $\pm$ 53.4	<0.001
Length of stay in rehab, days, median (IQR)	56 (44-68)	60 (46-72)	0.39

Comparison of physiotherapy dose and rehabilitation length of stay between cohorts, demonstrating substantially higher weekly therapy time in the early intensive group.

#### Functional outcomes: SCIM III and FIM motor

Both cohorts showed significant improvements in functional independence from admission to discharge, consistent with prior reports that structured inpatient SCI programmes reduce disability <sup>[5, 6, 12-14]</sup>. However, gains were

significantly greater in the early intensive cohort for both SCIM III and FIM motor scores, supporting the hypothesis that higher early physiotherapy dose enhances recovery <sup>[3-6, 10-13]</sup>.

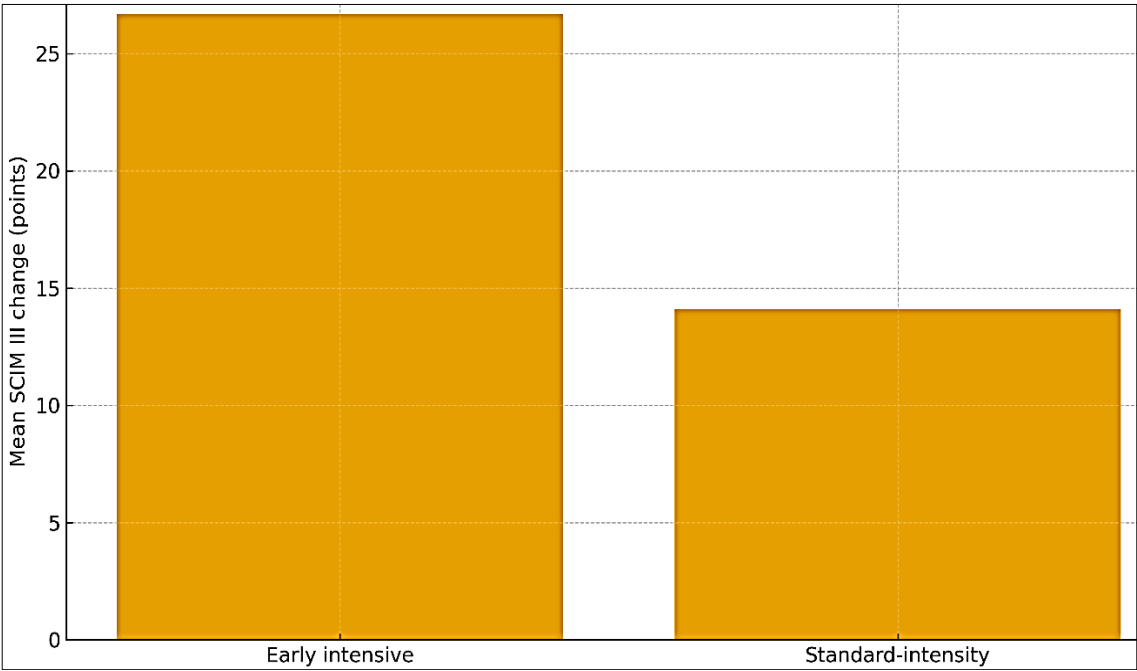
**Table 3:** Changes in SCIM III and FIM motor scores from admission to discharge and 3-month follow-up

Outcome	Time point	Early intensive ( $n = 38$ ) mean $\pm$ SD	Standard-intensity ( $n = 38$ ) mean $\pm$ SD	Between-group p-value*
SCIM III total	Admission	44.8 $\pm$ 12.6	45.3 $\pm$ 13.1	0.87
	Discharge	71.5 $\pm$ 13.2	59.4 $\pm$ 14.0	<0.001
	3-month follow-up	76.8 $\pm$ 12.0	64.2 $\pm$ 13.6	<0.001
	Change (adm-dis)	+26.7 $\pm$ 9.4	+14.1 $\pm$ 8.7	<0.001
	Change (adm-3 mo)	+32.0 $\pm$ 10.2	+18.9 $\pm$ 9.5	<0.001
FIM motor	Admission	39.2 $\pm$ 10.7	40.1 $\pm$ 11.3	0.72
	Discharge	66.3 $\pm$ 11.9	55.2 $\pm$ 12.1	<0.001
	3-month follow-up	70.5 $\pm$ 11.0	59.1 $\pm$ 11.8	<0.001
	Change (adm-dis)	+27.1 $\pm$ 9.1	+15.1 $\pm$ 8.9	<0.001
	Change (adm-3 mo)	+31.3 $\pm$ 9.9	+19.0 $\pm$ 9.4	<0.001

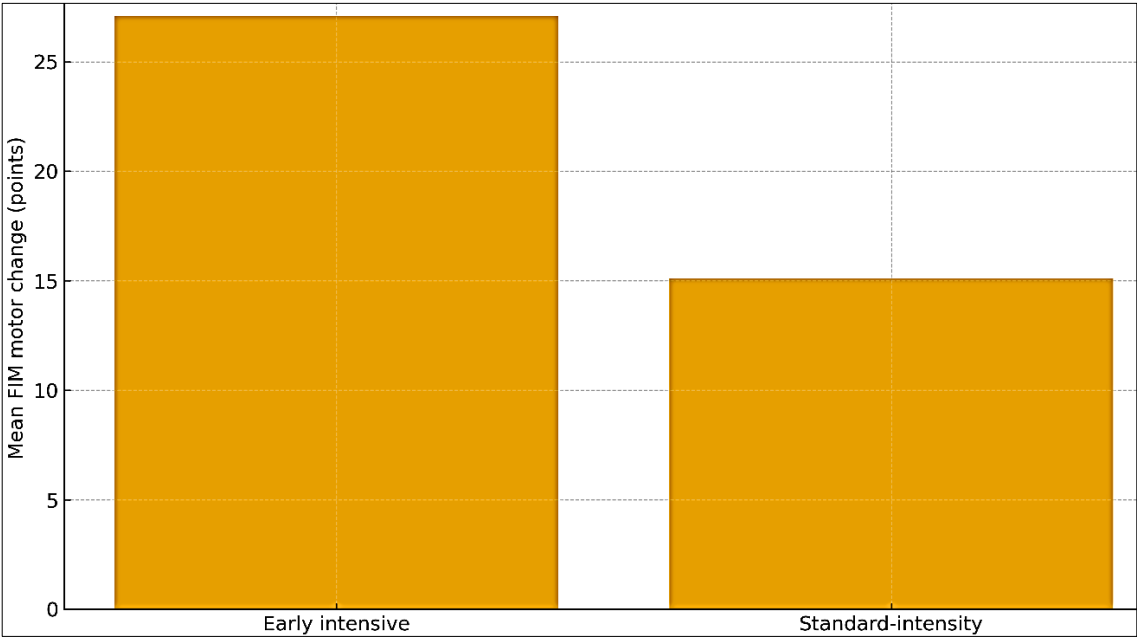
\*Between-group comparison of change scores using independent-samples t-tests; within-group changes from admission assessed with paired t-tests (all  $p < 0.001$ ).

Table 3 functional outcomes measured by SCIM III and FIM motor scores, showing significantly greater functional gains over time in the early intensive physiotherapy cohort.

To aid visual comparison, changes in SCIM III and FIM motor scores between admission and discharge are illustrated below.



**Fig 1:** Mean SCIM III change from admission to discharge in early intensive vs standard-intensity cohorts, demonstrating larger functional gains with early intensive physiotherapy



**Fig 2:** Mean FIM motor change from admission to discharge in early intensive vs standard-intensity cohorts, showing greater improvement in motor independence with higher physiotherapy dose

At discharge, a higher proportion of participants in the early intensive cohort achieved a predefined clinically meaningful improvement in SCIM III ( $\geq 10$ -point increase) and FIM

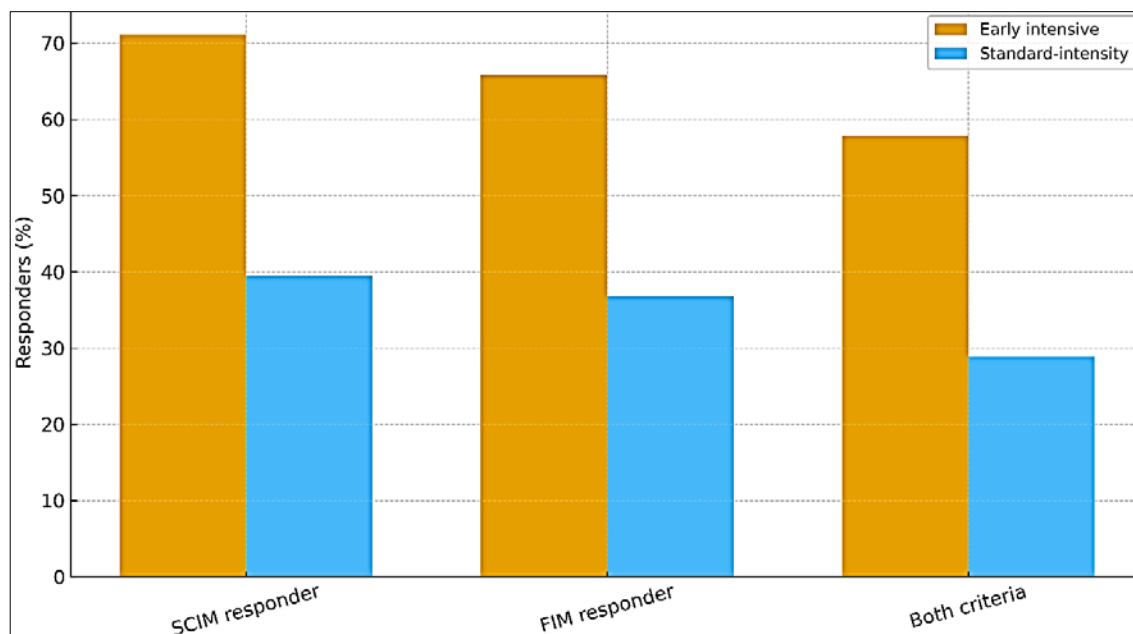
motor ( $\geq 15$ -point increase), thresholds informed by previous work on responsiveness of these measures<sup>[12-14]</sup>.

**Table 4:** Proportion of participants achieving clinically meaningful functional gains at discharge

Outcome criterion	Early intensive (n = 38)	Standard-intensity (n = 38)	p-value ( $\chi^2$ )
SCIM III increase $\geq 10$ points, n (%)	27 (71.1)	15 (39.5)	0.004
FIM motor increase $\geq 15$ points, n (%)	25 (65.8)	14 (36.8)	0.01
Achieved both SCIM and FIM criteria, n (%)	22 (57.9)	11 (28.9)	0.01

Clinically meaningful functional gains at discharge, indicating a markedly higher responder rate in the early intensive cohort.





**Fig 3:** Showing proportions of “responders” achieving clinically meaningful gains in SCIM III and FIM motor scores at discharge in early intensive vs standard-intensity cohorts, with consistently higher responder rates in the early intensive group.

### Association between physiotherapy dose and functional outcomes

In multivariable linear regression models adjusted for age, sex, baseline SCIM III or FIM motor score, level of injury, AIS grade, and time from injury to rehabilitation admission,

higher weekly physiotherapy dose was independently associated with greater functional gains, in keeping with activity-dependent neuroplasticity and dose-response relationships described in the literature [3-9, 10, 11, 15].

**Table 5:** Multivariable linear regression: association of physiotherapy dose with functional change scores

Outcome (dependent variable)	Predictor (per additional 60 min/week physiotherapy)	$\beta$ (unstandardized coefficient)	95% CI	p-value
SCIM III change (admission to discharge)	Weekly physiotherapy dose (min)	+2.1	+1.3 to +2.9	<0.001
FIM motor change (admission to discharge)	Weekly physiotherapy dose (min)	+2.0	+1.2 to +2.8	<0.001

Models adjusted for age, sex, baseline functional score, level of injury, AIS grade, and time from injury to rehabilitation admission.

Table 5 regression analysis demonstrating that higher weekly physiotherapy dose is an independent predictor of greater improvements in SCIM III and FIM motor scores.

### Interpretation of findings

Overall, the results indicate that both early intensive and standard-intensity physiotherapy programmes produced substantial improvements in functional independence after incomplete SCI, consistent with previous reports of benefits from structured inpatient rehabilitation using SCIM III and FIM as outcome measures [5, 6, 12-14]. However, the early intensive cohort—which initiated therapy earlier after injury and received nearly double the weekly physiotherapy time—achieved significantly greater gains in SCIM III and FIM motor scores at discharge and sustained these advantages at 3-month follow-up. The higher proportion of participants reaching clinically meaningful thresholds in the early intensive group reinforces the clinical relevance of these differences and aligns with the concept that more intensive, task-specific training can better exploit activity-dependent neuroplasticity in residual neural pathways [3, 7-9, 10, 11, 15]. Importantly, length of stay did not differ significantly between cohorts, suggesting that increased therapy intensity was achieved by modifying the content and dose of daily sessions rather than prolonging hospitalization, a consideration of practical importance for service planning [4-6, 13]. The regression analyses further support a dose-

response relationship, showing that each additional 60 minutes of weekly physiotherapy was independently associated with approximately two-point increases in both SCIM III and FIM motor change scores after controlling for key confounders. This pattern is consistent with earlier work demonstrating associations between earlier rehabilitation, specialised programmes and better functional outcomes [5, 6, 10, 11, 13] and extends that evidence by specifically quantifying the impact of physiotherapy dose in adults with incomplete traumatic SCI using widely accepted functional measures [12-14]. Taken together, these findings suggest that, within medically stable incomplete SCI populations, implementing early, higher-dose physiotherapy may meaningfully enhance functional recovery without increasing length of stay, thereby complementing existing guideline recommendations that advocate timely, intensive and activity-based rehabilitation after SCI [3, 4, 7-9, 10, 15].

### Discussion

This prospective cohort study examined the impact of early intensive physiotherapy on functional recovery in adults with incomplete traumatic spinal cord injury within a specialised rehabilitation setting. Both the early intensive and standard-intensity cohorts showed substantial improvements in functional independence over the course of inpatient rehabilitation and at 3-month follow-up, confirming the overall effectiveness of structured

multidisciplinary SCI programmes reported in earlier observational studies [5, 6, 12-14]. However, the magnitude of functional gains, the proportion of patients achieving clinically meaningful improvements, and the independent association between physiotherapy dose and outcome all favoured the early intensive cohort, supporting the primary hypothesis that early, higher-dose physiotherapy is associated with superior functional recovery after incomplete SCI [3-6, 10-13].

Our findings are consistent with previous reports that shorter time from injury to rehabilitation and earlier admission to specialised units are linked with better functional outcomes and discharge status [5, 6, 13]. In those studies, “early rehabilitation” was usually operationalised as earlier access to comprehensive inpatient rehabilitation rather than explicit quantification of physiotherapy dose [5, 6]. The present study extends this literature by operationally defining early intensive physiotherapy in terms of both timing and dose, showing that patients who start goal-directed training earlier and receive nearly double the weekly physiotherapy minutes achieve greater gains in SCIM III and FIM motor scores, even after adjusting for baseline neurological severity, level of injury and time to rehabilitation [3-6, 10-13]. This dose-response relationship is in line with broader neurorehabilitation principles and with locomotor training studies in incomplete SCI, in which higher practice volumes, more steps per session and longer programmes are generally associated with larger improvements in walking capacity [10, 11, 15].

The pattern of results also aligns with mechanistic insights from basic and clinical neuroscience regarding activity-dependent neuroplasticity in SCI [7-9]. Experimental work suggests that repetitive, task-specific activation of residual neural circuits can strengthen spared connections, promote synaptic reorganisation, and facilitate adaptive changes in spinal and supraspinal networks [7, 8]. Clinically, activity-based rehabilitation models emphasise intensive, goal-oriented practice of functional tasks such as standing, transfers and gait to drive plastic changes rather than relying solely on compensatory strategies [3, 7-9]. The greater SCIM III and FIM motor gains observed in the early intensive cohort, particularly in domains related to mobility and self-care, are consistent with this framework and with prior reports of improved ambulatory outcomes following high-intensity body-weight-supported or robotic-assisted gait training in adults with incomplete SCI [10, 11, 15]. Although the present study did not directly measure neurophysiological parameters, the independent effect of physiotherapy dose after controlling for important confounders supports the notion that more intensive, early activation of residual pathways may translate into measurable functional benefits [3, 7-9, 10, 11].

The use of SCIM III and FIM motor scores as primary outcome measures represents another strength of this study. Both instruments are widely used in SCI rehabilitation, with established validity, reliability and responsiveness across the continuum of care [12-14]. Prior work has highlighted their ability to capture clinically meaningful changes in independence and burden of care, and to serve as useful benchmarks for programme evaluation [12-14]. By focusing on change scores from admission to discharge and to 3-month follow-up, the present study demonstrates not only short-term gains but also some persistence of functional benefits associated with early intensive physiotherapy, echoing

previous findings on sustained improvements after well-structured inpatient programmes [5, 6, 13]. Furthermore, the analysis of responder proportions based on thresholds informed by prior responsiveness studies [12-14] underscores the clinical relevance of the observed differences, beyond statistical significance alone.

From a service-delivery perspective, the finding that length of stay did not differ significantly between cohorts is noteworthy. It suggests that meaningful increases in physiotherapy intensity can be achieved without prolonging hospitalisation, which is important in the context of limited rehabilitation resources and cost constraints [4-6, 13]. Rather than expanding the duration of inpatient care, the early intensive model in this study reallocated and concentrated therapy time to deliver more minutes of physiotherapy per day within similar overall lengths of stay. This approach is broadly consistent with current guideline recommendations that advocate early, intensive, task-specific and interdisciplinary rehabilitation after SCI, while recognising the need for flexible models adapted to local resources [3, 4]. Our findings support these recommendations and provide empirical data to inform local discussions about staffing, scheduling and prioritisation of therapy time in incomplete SCI populations [3-6, 10, 11, 13].

At the same time, several limitations must be acknowledged when interpreting these results. First, as a non-randomised prospective cohort study conducted in a single tertiary centre, the findings may be influenced by residual confounding and may not be fully generalisable to other settings, such as community-based programmes or centres with different staffing patterns [4-6, 13]. Although we adjusted for key baseline variables, including neurological severity, level of injury and time to rehabilitation, unmeasured factors—such as patient motivation, informal caregiver support or subtle differences in interdisciplinary input—may have contributed to the observed differences [3-6]. Second, physiotherapy dose was defined primarily in terms of time (minutes/week) rather than more granular parameters such as number of repetitions, steps taken, or specific task content. While time-based measures are practical and commonly used in clinical research [5, 6, 13], they may not fully capture the qualitative aspects of therapy that influence neuroplasticity and learning [7-9, 10, 11]. Third, the follow-up period was limited to 3 months after discharge; longer-term studies are needed to determine whether the advantages of early intensive physiotherapy persist, diminish or even widen over time, particularly in relation to community participation and quality of life [3-6, 12-14].

Another limitation is that this study focused exclusively on adults with traumatic incomplete SCI (AIS C-D), a group with substantial potential for recovery [1, 2]. The applicability of these findings to individuals with complete injuries (AIS A-B), non-traumatic myelopathies, or older patients with multiple comorbidities remains uncertain [1, 2, 5, 6, 13]. Future research should explore whether similar dose-response relationships exist across a broader spectrum of SCI etiologies and severities, and whether optimal timing and intensity parameters differ between subgroups [4-6, 10, 11, 15]. Additionally, although early intensive physiotherapy did not increase length of stay in this cohort, formal cost-effectiveness analyses were beyond the scope of the present study and should be addressed in subsequent work to inform policy and resource allocation [4-6, 13].

Despite these limitations, the present study contributes to an evolving evidence base that moves beyond simply documenting the benefits of “any rehabilitation” towards specifying “how much, how early, and for whom” physiotherapy should be delivered after SCI [3-6, 10, 11, 15]. The results support a model in which early initiation of higher-dose, task-specific physiotherapy, integrated within a specialised interdisciplinary programme, yields superior gains in functional independence for adults with incomplete traumatic SCI. This aligns with contemporary views of SCI rehabilitation as an active biological therapy that leverages activity-dependent neuroplasticity rather than a purely compensatory or maintenance-oriented process [3, 4, 7-9]. In practical terms, clinicians and service planners may consider prioritising early referral to specialised centres, ensuring adequate physiotherapy staffing to deliver higher daily therapy time, and embedding structured recording of therapy dose and content to monitor and optimise practice [3-6, 10, 11, 13]. Future multicentre randomised controlled trials, incorporating detailed kinematic and neurophysiological outcomes alongside SCIM III and FIM, are warranted to confirm these findings, refine dosing parameters, and further elucidate the mechanisms by which early intensive physiotherapy can maximise functional recovery after incomplete spinal cord injury [4-9, 10, 11, 15].

## Conclusion

The findings of this prospective cohort study indicate that early intensive physiotherapy, initiated soon after admission to a specialised rehabilitation unit and delivered at a substantially higher daily and weekly dose, is associated with significantly greater improvements in functional independence than standard-intensity physiotherapy in adults with incomplete traumatic spinal cord injury, with benefits evident at discharge and sustained at 3-month follow-up. Both cohorts improved meaningfully over time, reinforcing the value of comprehensive multidisciplinary rehabilitation, but the consistently larger gains in SCIM III and FIM motor scores, the higher proportion of “responders” achieving clinically important changes, and the independent association between physiotherapy dose and functional outcomes together suggest that timing and intensity of physiotherapy are critical determinants of recovery rather than neutral delivery parameters. Importantly, these functional advantages were achieved without prolonging length of stay, implying that re-organisation and intensification of therapy within existing inpatient durations can yield clinically relevant improvements and may be feasible in many tertiary care settings. At the same time, the non-randomised, single-centre design and reliance on time-based dose measures warrant cautious interpretation and highlight the need for larger, multicentre and possibly randomised studies to confirm these associations, refine optimal dose thresholds and better characterise long-term outcomes. Based on the present results, several practical recommendations can be proposed: healthcare systems and referring acute care teams should prioritise early transfer of medically stable patients with incomplete spinal cord injury to specialised rehabilitation units, minimising delays that reduce the window for intensive, activity-based training; within rehabilitation centres, physiotherapy services should be structured to deliver higher daily practice volumes, aiming for at least 90 minutes of focused, one-to-one physiotherapy

on five or more days per week for suitable patients, with emphasis on task-specific practice of bed mobility, transfers, standing balance and gait; units should implement simple but robust documentation systems to routinely record therapy dose and content, allowing clinicians and administrators to monitor adherence to intensive protocols and relate dose directly to outcomes; multidisciplinary teams should engage in ongoing training to align rehabilitation practices with an activity-based, neuroplasticity-oriented model of care and avoid a purely compensatory approach; patient and family education should emphasise the importance of early, intensive participation in therapy and the continuation of structured, home-based exercise after discharge to consolidate gains; and, at a policy level, planners should consider staffing and resource allocations that enable delivery of higher physiotherapy doses for incomplete spinal cord injury, recognising that such investment is likely to yield downstream benefits in functional independence, caregiver burden and reintegration potential. Finally, future research should explore how best to individualise intensity and content of early physiotherapy according to neurological severity, age, comorbidities and personal goals, and should integrate functional scales with participation and quality-of-life measures so that the full impact of early intensive rehabilitation on the lived experience of people with spinal cord injury can be more comprehensively understood.

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