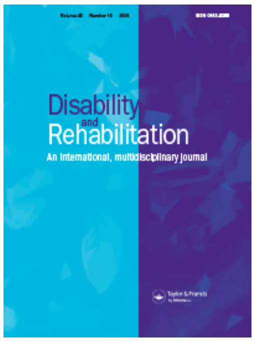


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# Blood pressure levels and clinically meaningful changes during inpatient rehabilitation after spinal cord injury: insights from the Dutch Spinal Cord Injury Database

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# Blood pressure levels and clinically meaningful changes during inpatient rehabilitation after spinal cord injury: insights from the Dutch Spinal Cord Injury Database

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**ABSTRACT**

**Purpose:** To examine in individuals with spinal cord injury (SCI): associations of blood pressure (BP) with demographic, injury, and medication characteristics at admission; changes in BP and heart rate (HR) between admission and discharge; and determinants of clinically meaningful BP changes during inpatient rehabilitation.

**Methods:** This retrospective cohort study used data from 1286 individuals with SCI admitted for inpatient rehabilitation. Resting systolic and diastolic BP (SBP, DBP), and HR were measured at admission and discharge.

**Results:** Most participants were male (63%, mean age of 58 years (SD 16)), and high-level (≥T6; 62%) motor incomplete (80%) SCI. At admission, higher SBP and DBP were associated with higher body mass index, lower neurological lesion level, and motor incomplete SCI; SBP with older age and anti-hypertensive medication use; and DBP with male sex. Between admission and discharge, mean BP and HR did not change, while hypertension and hypotension prevalence decreased. Older age (OR 1.02) and cardiovascular-related medication use (OR 1.97) were associated with clinically meaningful SBP increase, while anti-hypertensive medication use (OR 1.71) was associated with SBP decrease.

**Conclusions:** Despite unchanged mean BP in individuals with SCI during inpatient rehabilitation, BP levels at admission and changes were associated with demographic, injury, and medication-related factors.

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Blood pressure; cardiovascular diseases; heart disease risk factors; hypertension; hypotension; rehabilitation; spinal cord injuries

**IMPLICATIONS FOR REHABILITATION**

- Regular monitoring of blood pressure (BP) and heart rate is essential during spinal cord injury (SCI) rehabilitation, as one in five individuals still had elevated BP at discharge.
- Older males with higher body mass index, low-level incomplete injuries, and those using anti-hypertensives require special attention for early BP management.
- Addressing BP during inpatient rehabilitation may improve long-term health outcomes for individuals with SCI.

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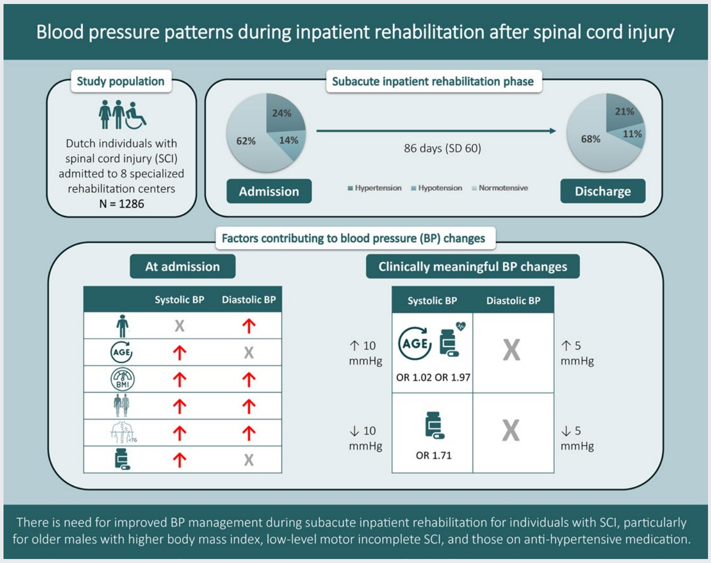
**GRAPHICAL ABSTRACT**




## Introduction

The spinal cord transmits signals between the brain and the body. A spinal cord injury (SCI) can interrupt these signals, resulting in various motor, sensory, and autonomic dysfunctions [1]. Such impairments are associated with a markedly increased risk of secondary health conditions in individuals with SCI, including cardiovascular disease (CVD) [2–4]. For example, impaired descending sympathetic vascular control contributes to fluctuations in vascular resistance and altered plasma catecholamine releases, leading to blood pressure (BP) instabilities such as hypotension and episodes of uncontrolled hypertension (autonomic dysreflexia), as well as heart rate (HR) abnormalities like bradycardia [5,6]. These issues are more prevalent in individuals with SCI at higher lesion levels (at or above thoracic level 6, ≥T6), but they may occur at any injury level [7]. BP fluctuations and abnormal HR contribute to the increased risk of CVD, the leading cause of mortality in this population [8]. This highlights the importance of understanding BP status following SCI.

A systematic review including studies on cardiovascular function in individuals with SCI, including BP status, has shown that most research has focused on the chronic phase of the injury [9]. However, the cardiovascular system undergoes marked and rapid adaptations shortly after SCI [10]. For instance, within six weeks following injury, a 30% reduction in the size of conduit arteries below the lesion level has been reported [11]. Considering that CVD prevention should start as early as possible, understanding the timeline of BP changes following injury is important [12]. Nonetheless, there is limited knowledge about BP status during the subacute phase after SCI [9].

In addition to this knowledge gap, the demographics of the SCI population have shifted over the past decades, toward an increasing number of older individuals experiencing non-traumatic, incomplete, cervical SCI [13,14]. This shift has led to increased heterogeneity in factors that may influence cardiovascular function, including age, sex, body mass index (BMI), injury-related characteristics, and medication use. Previous research suggests that older age and higher neurological level of injury are both related to impaired BP status in the SCI population [15]. Furthermore, medication use in individuals with SCI influencing BP and HR is high, with many individuals receiving anti-hypertensive or other cardiovascular medication, often in the context of polypharmacy [16–18]. This is important to consider, as such medications may directly affect BP regulation and HR responses. In addition, factors such as sex and BMI may further contribute to variability in BP and HR outcomes within the SCI population [17,19]. Together, this demographic shift underscores the need for an updated and comprehensive understanding of BP status following SCI as part of the existing care.

Therefore, the aim of this study was to determine in individuals with SCI: (1) the association between resting BP at admission to subacute inpatient rehabilitation and demographic factors, SCI-specific characteristics, and medication use; (2) the longitudinal changes in BP and HR from admission to discharge during inpatient rehabilitation; and (3) the factors contributing to clinically meaningful changes in BP during the subacute inpatient rehabilitation period.

## Methods

### *Participants*

A retrospective cohort study was performed utilizing data from the Dutch Spinal Cord Injury Database (DSCID) [20]. The DSCID contains data from individuals with both complete and incomplete SCI, admitted to one of the eight specialized SCI rehabilitation centers in the Netherlands between 2015 and 2022. Participants were admitted between January 2015 and August 2022, with discharges occurring between January 2015 and September 2022. This database provides a broad representation of the current population of individuals with SCI in the Netherlands, although it does not capture those not referred to these centers.

The inclusion criteria for the study required documented measurements of systolic BP (SBP), diastolic BP (DBP), and HR at both admission and discharge from the subacute inpatient rehabilitation program. An additional inclusion criterion was the availability of documented neurological classification at the time of admission, performed according to the International Standards for Neurological Classification of SCI (ISNCSCI) [21]. Individuals with SCI were eligible if they were admitted for their initial subacute inpatient rehabilitation phase within nine months after SCI onset, thereby excluding re-admissions. Participants also had to be 18 years or older.

### *Procedure*

This study adhered to the principles outlined in the Declaration of Helsinki. The procedure of obtaining informed consent varied among the rehabilitation centers. In certain centers, eligible individuals with SCI were asked to provide informed consent in advance. In other centers, individuals were informed about the use of anonymized data for research purposes, and were given the opportunity to decline the use of their data [20]. The executive boards of all participating centers agreed to provide anonymized data to the DSCID.

As part of routine care, clinical data was collected and documented in the medical records according to the protocol of each rehabilitation center. Standardized clinical data was systematically extracted at both admission and discharge using a web-based data entry platform. The responsibility for data collection was assigned to a designated member of the clinical team at each rehabilitation center. These individuals extracted the required data from the medical records and, when necessary, engaged with the participants to obtain additional information. Authorized healthcare professionals within each center had access to the platform. Subsequently, a researcher from the DSCID steering committee organized and structured the data, extracting the requested specific parameters essential for this study.

### *Outcomes*

Demographic information at admission was extracted from the DSCID, including sex, age, and BMI. Furthermore, injury-related characteristics were systematically collected, including etiology, neurological level of injury and completeness at admission, time since injury, and inpatient rehabilitation length of stay. The neurological level and completeness of the lesion were assessed using the ISNCSCI [21]. Motor completeness was defined using the American Spinal Injury Association Impairment Scale (AIS) categories A and B, while motor incompleteness was defined as AIS grades C and D. Preexisting CVD was extracted from the DSCID, as outlined by the International SCI Cardiovascular Function Basic Data Set [22]. This provided background information on pre-SCI cardiovascular conditions and risk factors, such as cardiac pacemaker, prior cardiac surgery, hypertension, hypotension, orthostatic hypotension, deep vein thrombosis, myocardial infarction, and stroke. The dataset also included information about medications used by participants that could potentially influence cardiovascular functions, such as anti-hypertensives, anti-hypotensive medication, and other medications relevant to CVD risk (e.g., beta-blockers, anti-arrhythmics, and angiotensin-converting enzyme inhibitors), along with the use of compression devices (e.g., abdominal binders or compression stockings).

The parameters SBP, DBP, and HR at admission and discharge of the rehabilitation period were also extracted from the DSCID, with BP and HR values based on a single measurement obtained as part of routine clinical care at the start and end of the inpatient rehabilitation period. Measurements were performed in either sitting or supine position, although in a small subset the measurement position was not documented. In addition, mean arterial pressure (MAP) was calculated by doubling DBP, adding it to SBP, and then dividing the sum by three [23]. BP thresholds were defined according to the International Standards to document Autonomic Function following Spinal Cord Injury (ISAFSCI), with hypertension defined as SBP exceeding 140 mmHg and/or DBP surpassing 90 mmHg, and hypotension as SBP less than 90 mmHg and/or DBP less than 60 mmHg [24].

### Statistical analysis

Data analysis was performed using R (version 4.4.2; R Core team, 2025, Vienna, Austria). Descriptive statistics were used to summarize participant characteristics. Continuous variables were presented as mean, standard deviation, and range, while categorical variables were expressed as counts and percentages.

Addressing the first research question, univariate regression models were used to identify potential associations ($p < 0.1$) between SBP and DBP at admission and the following variables (based on previous studies [15–17,19,25]): sex, age, BMI, lesion level (categorized as high (≥T6) or low (<T6)), motor completeness of the lesion (complete versus incomplete), etiology (traumatic versus non-traumatic), and medication use (anti-hypertensives, anti-hypotensive medication, and other medications relevant to CVD risk). Variance inflation factors were quantified, but no notable multicollinearity (all <2) was observed. Subsequently, a multivariate regression analysis was performed, incorporating all variables from the univariate analyses with $p < 0.1$, to identify independent predictors of SBP and DBP at the start of the inpatient rehabilitation.

Second, changes in SBP, DBP, MAP, and HR between admission and discharge of the inpatient rehabilitation period were evaluated using a paired *t*-test. Furthermore, McNemar's test was used to evaluate differences in prevalence of hypertension and hypotension during the rehabilitation period.

For the third research question, clinically meaningful change in BP was defined as an increase or decrease of ≥10 mmHg in SBP and/or ≥5 mmHg in DBP, reflecting clinically relevant thresholds [26]. Based on this definition, BP was dichotomized into clinically meaningful change versus stable BP. Logistic regression models were fitted to estimate odds ratios for the aforementioned variables, using individuals with stable BP as the reference group. The threshold for statistical significance was set at $p < 0.05$ for all statistical analyses.

## Results

### Participant characteristics

Among the cohort of 3397 individuals with SCI included in the DSCID, 1286 met the inclusion criteria for this study. The schematic representation of the participant inclusion flow is shown in Figure 1.

Table 1 presents an overview of participant demographics and SCI characteristics. Participants were predominantly male (63%), with an average age of 58 years (SD 16) at the time of admission. The primary etiology of SCI was non-traumatic (64%), while the most prevalent cause was falls (62%). At admission, 62% of the participants presented with a high lesion level (≥T6). The majority of participants had a motor incomplete SCI (80%), with AIS D being the most frequently observed category (66%). The average time between the onset of SCI and admission to the rehabilitation center was 39 days (SD 47), and the average inpatient rehabilitation duration was 86 days (SD 59). Hypertension represented the most prevalent pre-SCI CVD risk factor, reported in 39% of the cohort.

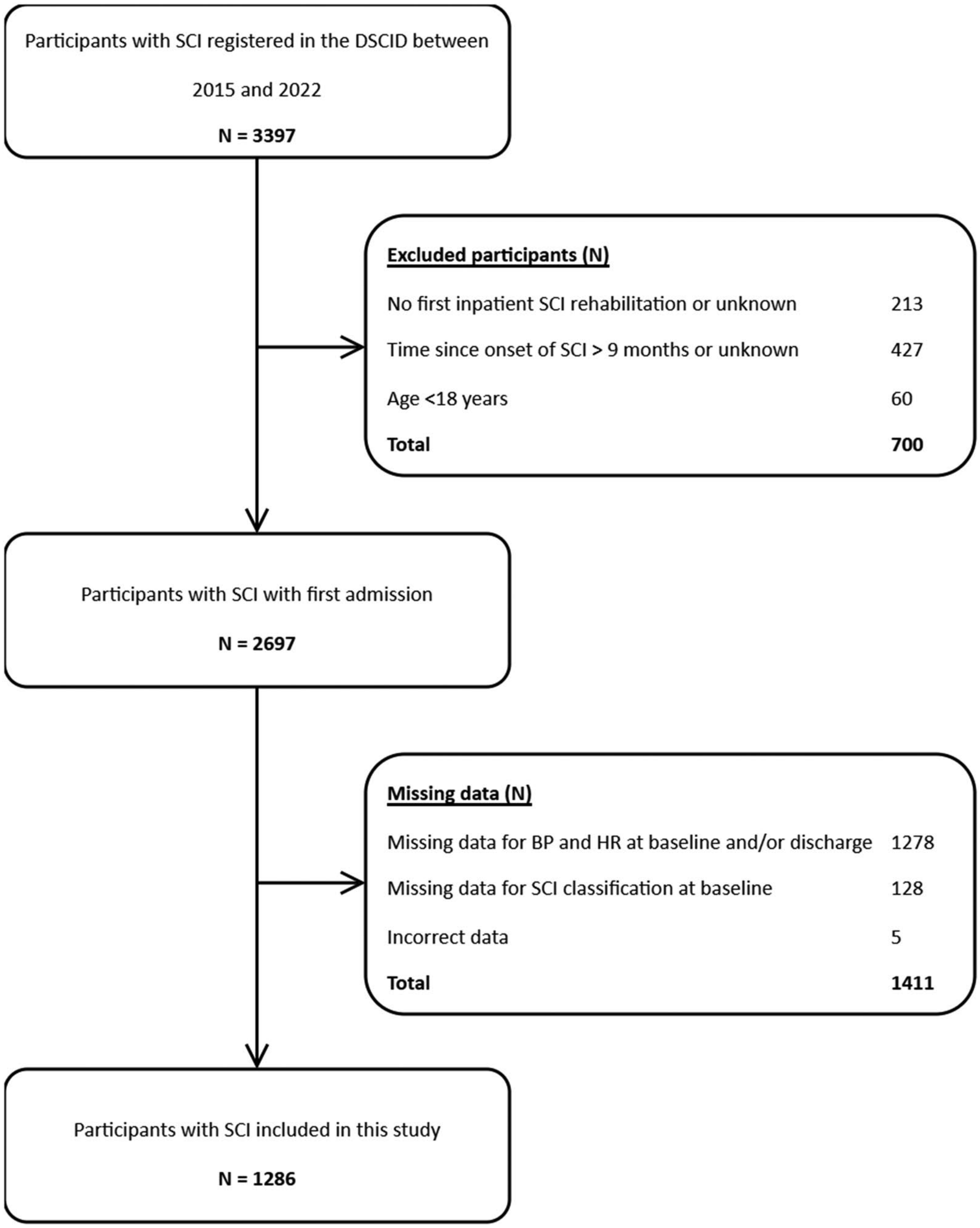



**Figure 1.** Flowchart of the participants. BP: blood pressure; DSCID: Dutch Spinal Cord Injury Database; HR: heart rate; SCI: spinal cord injury.

Regarding medication use, 31% of participants were using anti-hypertensive drugs at admission and 34% at discharge. Anti-hypotensive drugs were used by 2% of participants at admission and 1% at discharge. Additionally, 21% of participants were taking other medications relevant to CVD risk (e.g., beta-blockers, anti-arrhythmics, and angiotensin-converting enzyme inhibitors) at both admission and discharge.

## *Associations with resting BP at admission*

Mean resting SBP at admission was 126 mmHg (SD 18) and demonstrated positive associations with age, BMI, lesion level, completeness of the injury, etiology, and use of anti-hypertensive drugs as outlined in Table 2 ($p$ < 0.1). A negative association was found with anti-hypotensive medication in the univariate regression model. In the multivariate linear regression model, age, BMI, lesion level, completeness of the

**Table 1.** Characteristics of the participants at admission.

| | N | |
|---|---|---|
| *Demographic characteristics* | | |
| Sex, N (%) | 1286 | |
| Male | | 809 (63) |
| Female | | 477 (37) |
| Age (years), mean (SD) [range] | 1286 | 58 (16) [18–90] |
| Body mass index (kg/m$^2$), mean (SD) [range] | 888 | 26.1 (5.2) [14.8–62.4] |
| *SCI characteristics* | | |
| Neurological level of injury, N (%) | 1286 | |
| Cervical (C1–C7) | | 567 (44) |
| High thoracic (T1–T6) | | 235 (18) |
| Low thoracic (T7–T12) | | 302 (23) |
| Lumbar (L1–L5) | | 179 (14) |
| Sacral (S1–S5) | | 3 (0.2) |
| AIS classification, N (%) | 1286 | |
| AIS A | | 143 (11) |
| AIS B | | 110 (9) |
| AIS C | | 180 (14) |
| AIS D | | 853 (66) |
| Etiology of SCI, N (%) | 1265 | |
| Traumatic | | 459 (36) |
| Sports | | 47 (10) |
| Violence | | 2 (0.4) |
| Traffic accident | | 105 (23) |
| Fall | | 283 (62) |
| Other traumatic cause | | 22 (5) |
| Non-traumatic | | 806 (63.7) |
| Vascular | | 167 (21) |
| Oncology | | 183 (23) |
| Inflammation | | 136 (17) |
| Vertebral degeneration | | 183 (23) |
| Congenital | | 1 (0.1) |
| Other non-traumatic cause | | 136 (17) |
| Time since injury (days), mean (SD) [range] | 1286 | 39 (47) [3–303] |
| Inpatient rehabilitation length of stay (days), mean (SD) [range] | 1250 | 86 (59) [5–504] |
| Pre-SCI cardiovascular conditions and risk factors, N (%)[a] | 924 | |
| None | | 468 (51) |
| Hypertension | | 357 (39) |
| Hypotension | | 7 (0.8) |
| Cardiac pacemaker | | 11 (1) |
| Prior cardiac surgery | | 34 (4) |
| Orthostatic hypotension | | 4 (0.4) |
| Deep vein thrombosis | | 24 (3) |
| Myocardial infarction | | 4 (0.4) |
| Stroke | | 5 (0.5) |
| Other cardiac conditions | | 72 (8) |

AIS: American Spinal Injury Association Impairment Scale; SCI: spinal cord injury.
[a]Multiple conditions can exist within one participant; therefore, total percentages can exceed 100%.

injury, and the use of anti-hypertensive drugs continued to exhibit positive associations with SBP ($p < 0.05$).

At admission, resting DBP was 73 mmHg (SD 11) and showed positive associations with BMI, lesion level, completeness of the injury, etiology, and the use of anti-hypertensive medications as displayed in Table 3 ($p < 0.1$). Negative associations were observed with female sex and anti-hypotensive drugs in the univariate regression models. In the multivariate regression model, positive associations persisted for BMI, lesion level, and completeness of the injury, while female sex was associated with lower DBP in the multivariate regression model ($p < 0.05$).

### *Longitudinal changes in BP and HR during the inpatient rehabilitation period*

The paired *t*-test revealed no statistically significant differences in SBP, DBP, and HR between admission and discharge, as illustrated in Figure 2 and Supplementary Table S1. MAP at admission was 91 mmHg (SD 12) and did not significantly change at discharge (91 mmHg (SD 11), $p = 0.48$). However, the prevalence of hypertension significantly decreased from admission (24%) to discharge (21%) ($p < 0.05$). Similarly, the prevalence of hypotension significantly declined from admission (14%) to discharge (11%) ($p < 0.05$).

**Table 2.** Associations between systolic blood pressure and participant characteristics.

| Systolic blood pressure at admission | | | | | | |
|---|---|---|---|---|---|---|
| | Univariate | | | Multivariate | | |
| Factors | $\beta$ | 95% confidence interval | $p$ Value | $\beta$ | 95% confidence interval | $p$ Value |
| Female sex[a] | −0.90 | −2.93 to 1.12 | 0.38 | | | |
| Age, years | 0.22 | 0.16–0.28 | **<0.001*** | 0.13 | 0.06–0.20 | **<0.001**** |
| BMI, kg/m$^2$ | 0.63 | 0.41–0.85 | **<0.001*** | 0.45 | 0.23–0.67 | **<0.001**** |
| Low lesion level (<T6)[a] | 3.56 | 1.54–5.57 | **<0.001*** | 3.71 | 1.34–6.07 | **0.002**** |
| Incomplete SCI[a] | 5.25 | 2.80–7.70 | **<0.001*** | 3.35 | 0.50–6.20 | **0.021**** |
| Non-traumatic SCI[a] | 4.89 | 2.87–6.92 | **<0.001*** | 0.48 | −1.97 to 2.92 | 0.70 |
| Use of anti-hypertensives drugs[a] | 9.50 | 7.35–11.66 | **<0.001*** | 7.10 | 4.44–9.77 | **<0.001**** |
| Use of anti-hypotensive drugs[a] | −16.55 | −24.06 to (−9.05) | **<0.001*** | −6.82 | −17.25 to 3.61 | 0.20 |
| Use of other medications relevant to CVD risk[a] | 0.98 | −1.59 to 3.56 | 0.46 | | | |

*$p < 0.1$ indicates a significant association in univariate analyses.
**$p < 0.05$ indicates a significant association in multivariate analyses.
[a]For categorical variables with two levels, the comparator category is specified in the table, and the other category serves as the reference group.
SCI=spinal cord injury; CVD=cardiovascular disease.

**Table 3.** Associations between diastolic blood pressure and participant characteristics.

| Diastolic blood pressure at admission | | | | | | |
|---|---|---|---|---|---|---|
| | Univariate | | | Multivariate | | |
| Factors | $\beta$ | 95% confidence interval | $p$ Value | $\beta$ | 95% confidence interval | $p$ Value |
| Female sex[a] | −2.24 | −3.51 to (−0.98) | **<0.001*** | −2.14 | −3.64 to (−0.64) | **0.006**** |
| Age, years | −0.01 | −0.04 to 0.03 | 0.73 | | | |
| BMI, kg/m$^2$ | 0.29 | 0.16–0.43 | **<0.001*** | 0.24 | 0.10–0.38 | **<0.001**** |
| Low lesion level (<T6)[a] | 2.90 | 1.64–4.16 | **<0.001*** | 3.01 | 1.48–4.53 | **<0.001**** |
| Incomplete SCI[a] | 2.61 | 1.07–4.15 | **<0.001*** | 2.09 | 0.26–3.92 | **0.026**** |
| Non-traumatic SCI[a] | 2.78 | 1.51–4.05 | **<0.001*** | 1.01 | −0.57 to 2.60 | 0.21 |
| Use of anti-hypertensives drugs[a] | 2.14 | 0.76–3.53 | **0.002*** | 1.56 | −0.09 to 3.21 | 0.06 |
| Use of anti-hypotensive drugs[a] | −6.45 | −11.17 to (−1.72) | **0.008*** | −4.34 | −11.08 to 2.40 | 0.21 |
| Use of other medications relevant to CVD risk[a] | −0.38 | −1.99 to 1.24 | 0.65 | | | |

*$p < 0.1$ indicates a significant association in univariate analyses.
**$p < 0.05$ indicates a significant association in multivariate analyses.
[a]For categorical variables with two levels, the comparator category is specified in the table, and the other category serves as the reference group.
SCI=spinal cord injury; CVD=cardiovascular disease.

Additional parameters that could influence BP changes during the rehabilitation period include the use of compression devices and the position in which BP measurements were taken. At admission, 8% of the participants utilized compression devices, compared to 11% at discharge. Furthermore, while most BP measurements at admission were conducted in supine position (66%), most measurements at discharge were performed in sitting position (63%). The measurement position was not documented in 27% of participants at admission and 28% at discharge.

### *Factors contributing to clinically meaningful changes in BP*

Overall, 1008 participants (78%) exhibited a clinically meaningful change in either SBP (≥10 mmHg) or DBP (≥5 mmHg) during inpatient rehabilitation. Of these, 304 participants (24%) showed a clinically meaningful increase in SBP, while 353 participants (27%) demonstrated a clinically meaningful decrease. For DBP, 418 participants (33%) exhibited a clinically meaningful increase, and 429 participants (33%) showed a decrease during this period. Among participants who exhibited a clinically meaningful change in BP, 127 (13%) transitioned from no hypertension at admission to hypertension at discharge, and 81 (8%) from no hypotension to hypotension at discharge. Conversely, 158 participants (16%) with hypertension at admission no longer met the criteria at discharge, and 114 participants (11%) with hypotension at admission were no longer classified as hypotensive.

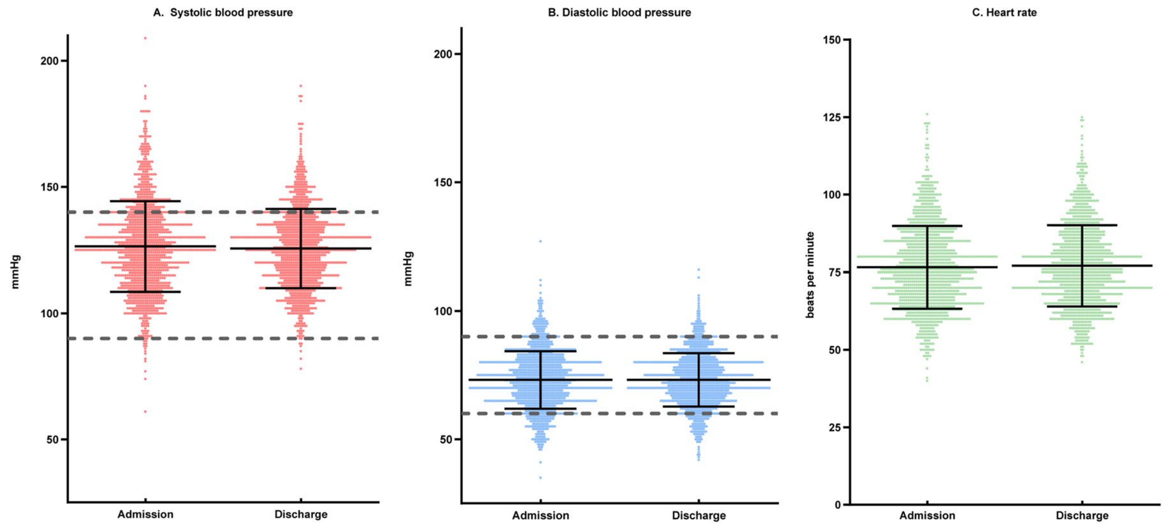



**Figure 2.** Scatterplots of systolic and diastolic blood pressure and heart rate at admission and discharge. The scatterplots illustrate the admission and discharge values for systolic blood pressure (A), diastolic blood pressure (B), and heart rate (C). Error bars represent SD, with the mean value indicated by the black horizontal line. Dashed grey horizontal lines illustrate clinical thresholds of hypertension and hypotension.

**Table 4.** Adjusted odds ratios of factors contributing to clinical meaningful changes in systolic and diastolic blood pressure during the subacute inpatient rehabilitation period.

| | Systolic blood pressure increase of ≥10 mmHg *N* = 304 | | | Systolic blood pressure decrease of ≥10 mmHg *N* = 353 | | |
|---|---|---|---|---|---|---|
| Factors | Odds ratio (adjusted) | 95% confidence interval | *p* Value | Odds ratio (adjusted) | 95% confidence interval | *p* Value |
| Female sex[a] | 0.93 | 0.64–1.33 | 0.67 | 0.98 | 0.70–1.37 | 0.91 |
| Age, years | 1.02 | 1.00–1.03 | **0.007*** | 1.00 | 0.99–1.01 | 0.98 |
| BMI, kg/m$^2$ | 0.98 | 0.95–1.02 | 0.33 | 1.01 | 0.98–1.04 | 0.44 |
| Low lesion level (<T6)[a] | 1.11 | 0.77–1.61 | 0.57 | 1.34 | 0.96–1.88 | 0.09 |
| Incomplete SCI[a] | 0.56 | 0.36–0.87 | **0.010*** | 0.74 | 0.49–1.13 | 0.16 |
| Non-traumatic SCI[a] | 1.07 | 0.73–1.59 | 0.72 | 0.98 | 0.68–1.39 | 0.90 |
| Use of anti-hypertensives drugs[a] | 1.20 | 0.79–1.82 | 0.40 | 1.71 | 1.16–2.53 | **0.007*** |
| Use of anti-hypotensive drugs[a] | 1.06 | 0.20–5.50 | 0.95 | 0.71 | 0.14–3.60 | 0.68 |
| Use of other medications relevant to CVD risk[a] | 1.97 | 1.26–3.06 | **0.003*** | 1.32 | 0.85–2.04 | 0.22 |
| | Diastolic blood pressure increase of ≥5 mmHg *N* = 418 | | | Diastolic blood pressure decrease of ≥5 mmHg *N* = 429 | | |
| Factors | Odds ratio (adjusted) | 95% confidence interval | *p* Value | Odds ratio (adjusted) | 95% confidence interval | *p* Value |
| Female sex[a] | 1.09 | 0.77–1.53 | 0.64 | 1.13 | 0.81–1.60 | 0.47 |
| Age, years | 1.01 | 1.00–1.02 | 0.17 | 1.00 | 0.99–1.01 | 0.54 |
| BMI, kg/m$^2$ | 0.98 | 0.95–1.02 | 0.26 | 1.03 | 1.00–1.06 | 0.06 |
| Low lesion level (<T6)[a] | 1.10 | 0.78–1.57 | 0.58 | 1.27 | 0.90–1.80 | 0.18 |
| Incomplete SCI[a] | 0.88 | 0.58–1.34 | 0.55 | 1.21 | 0.79–1.86 | 0.39 |
| Non-traumatic SCI[a] | 1.00 | 0.70–1.45 | 0.98 | 0.93 | 0.65–1.33 | 0.69 |
| Use of anti-hypertensives drugs[a] | 0.81 | 0.53–1.22 | 0.31 | 1.10 | 0.74–1.63 | 0.64 |
| Use of anti-hypotensive drugs[a] | 0.37 | 0.07–1.87 | 0.23 | 0.39 | 0.08–1.99 | 0.26 |
| Use of other medications relevant to CVD risk[a] | 1.09 | 0.70–1.70 | 0.70 | 0.91 | 0.59–1.42 | 0.69 |

*$p < 0.05$.
[a]For categorical variables with two levels, the comparator category is specified in the table, and the other category serves as the reference group.
SCI=spinal cord injury; CVD=cardiovascular disease.

Table 4 presents the odds ratios and 95% confidence intervals for factors associated with clinically meaningful changes in BP. A clinically meaningful increase in SBP was associated with older age and the use of other medications relevant to CVD risk. Motor incomplete SCI was associated with a decreased probability of an SBP increase. Additionally, the use of anti-hypertensive drugs was associated with a clinically relevant decrease in SBP.

## Discussion

In this extensive retrospective study, we examined BP and HR in 1286 individuals with SCI during the subacute inpatient rehabilitation phase. First, we found a mean resting SBP of 126 mmHg (SD 18) and DBP of 73 mmHg (SD 11) at admission, with several factors being related to elevated BP, including male sex (DBP only), older age (SBP only), higher BMI, motor incomplete lesions below T6, and the use of anti-hypertensive drugs (SBP only). Second, we found no longitudinal changes in BP or HR over the course of the inpatient rehabilitation period, although the prevalence of both hypertension and hypotension decreased over time. Third, clinically meaningful BP changes during the inpatient rehabilitation period were observed in 78% of individuals. A higher risk of SBP increase was associated with older age and the use of other medications relevant to CVD risk, while SBP decrease was linked to the use of anti-hypertensive medication. Taken together, this study underscores the frequent presence of BP abnormalities and the importance of BP monitoring during the subacute inpatient rehabilitation period, particularly in older men, individuals with a higher BMI, those with motor incomplete SCI below T6, and individuals using anti-hypertensive medications.

In the present study, 24% of the study population demonstrated hypertension at admission. This percentage is comparable to that observed in the chronic Dutch SCI population, but is clinically highly relevant since presence of hypertension is associated with increased risk of CVD [3,4,15]. Moreover, older age, male sex, and higher BMI were associated with elevated SBP and/or DBP. These findings are consistent with associations observed in the general population [27–29]. Furthermore, the finding that elevated BP was observed among individuals prescribed anti-hypertensive medications is not surprising, as such treatment is typically indicated for managing hypertension. Our study confirms that these demographic risk factors are also applicable to individuals with SCI during subacute rehabilitation. Although previous studies in the SCI population have reported similar associations, they often focused on younger and/or substantially smaller cohorts [30,31]. Considering the shifting demographic trends in the SCI population, our findings are clinically relevant and highlight the relatively high prevalence of BP abnormalities in the SCI population [13,14].

The observation that traditional risk factors were related to BP levels may not be surprising given the relatively short duration between the onset of the lesion and the measurements. Interestingly, we also found associations between SCI characteristics and BP at admission. Specifically, individuals with lower injury levels (<T6) and motor incomplete lesions showed higher SBP and DBP. This may be attributed to the disruption of descending spinal sympathetic pathways in individuals with higher injury levels and motor complete SCI, leading to lower resting vascular tone in a relatively large vascular bed [5]. Such changes may, at least in part, contribute to lower resting BP in individuals with higher lesion levels [6]. Consistent with previous research in individuals with chronic SCI, our data pertaining to the subacute phase of the injury reinforces the immediate impact of an SCI on the cardiovascular system [9,15].

In the context of BP monitoring during the subacute inpatient rehabilitation period, we observed no longitudinal changes in BP values in a substantial group of individuals with SCI. This observation aligns with the results reported by Raguindin et al., although their study had a substantially smaller sample size and excluded participants with known CVD [12]. This distinction is particularly relevant given the rapidly changing demographics of the SCI population, as reflected in our cohort, where approximately 50% of participants had a history of CVD and/or were at increased risk for CVD.

Although mean BP levels did not change, we observed a reduction in the prevalence of both hypertension and hypotension. This decrease may be explained by the wider range of BP values at admission compared to discharge. These findings likely reflect the injury phase, as individuals in the subacute phase of SCI may experience natural physiological stabilization and BP normalization [32].

Despite the absence of overall longitudinal changes, at least 78% of our study population showed clinically significant variations in BP. This raises the question which factors might relate to these clinically meaningful changes in BP during the subacute rehabilitation period. Our analysis indicated that older individuals and those using other medications relevant to CVD risk were more likely to experience a clinically meaningful increase in SBP. This reinforces the relevance of our previous observation that age is associated with higher SBP at admission, underscoring the influence of age on BP dynamics during the subacute rehabilitation period. Furthermore, individuals with motor complete SCI were less likely to show an increase in SBP compared to those with incomplete lesions. This distinction can be explained by the nature of SCI; in individuals with motor complete SCI, the spinal cord damage is more extensive, and the likelihood of recovery of motor function is limited [33]. In contrast, individuals with motor incomplete SCI have a higher chance of spontaneous neurological recovery, which can lead to improved autonomic function and, subsequently, changes in BP [33].

### *Study limitations*

It is noteworthy that this large-scale study provides a unique and comprehensive overview of BP in Dutch individuals with SCI, covering various lesion levels and completeness, which adds valuable insights to the existing literature. However, this study has some limitations that need to be discussed. First, we have a relatively large number of missing data (52%), primarily due to the absence of relevant information in the medical records. However, to our knowledge, our study still represents the largest database on BP changes during the inpatient rehabilitation phase for individuals with SCI. A second limitation is that BP measurements were based on a single clinical measurement, which may not fully capture BP variability or positional changes. In addition, the position in which BP measurements were obtained was not documented for a substantial proportion of participants (≈27%). As measurement position may influence BP values, this may have introduced variability in the results. However, post hoc analyses revealed no differences in outcomes when comparing individuals who were measured in the same position at admission and discharge. Finally, although several relevant demographic and clinical variables were included based on prior literature, we may not have captured all factors that could influence BP status in individuals with SCI. Future research could further explore the role of additional characteristics on BP in this population.

## Conclusions

The findings of the DSCID highlight the importance of considering demographic and clinical characteristics when evaluating BP in individuals with SCI during inpatient rehabilitation. Factors such as sex, age, BMI, injury characteristics, and medication use were associated with BP status at admission. Although BP remained largely stable during rehabilitation at the group level, the prevalence of hypertension showed a small decrease while remaining substantial. Males who were olderand used anti-hypertensive of other cardiovascular medication more often showed clinically meaningful changes in BP. Our findings underscore the critical need for enhanced attention to BP management during the subacute inpatient rehabilitation period for individuals with SCI, particularly in the context of demographic shifts within the SCI population, characterized by an increasing proportion of older individuals and those with more comorbidities. Early identification and intervention could be key to mitigate long-term cardiovascular risks in this vulnerable population.

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CRediT: **Maxime J. van Oort**: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Project administration, Software, Validation, Visualization, Writing – original draft, Writing – review & editing; **Ilse J. W. van Nes**: Conceptualization, Funding acquisition, Methodology, Project administration, Supervision, Validation, Writing – review & editing; **Maria T. E. Hopman**: Funding acquisition, Methodology, Supervision, Validation, Writing – review & editing; **Dick H. J. Thijssen**: Methodology, Supervision, Validation, Writing – review & editing; **Tijn van Diemen**:

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